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Polycentricity, Performance and Planning

Concepts, Evidence and Policy in Barcelona, Catalonia

Jaume Masip-Tresserra

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To my parents, Jaume and Elionor, and my brother, Oriol.

Preface

Whereas strategy is abstract and based on long-term goals, tactics are concrete and based on finding the best move right now.
Questions are what matter. Questions, and discovering the right ones, are the key to staying on course. [...] The wave of information threatens to obscure strategy, to drown it in details and numbers, calculation and analysis.
To have strong tactics, we must have strong strategy on one side and accurate calculation on the other. Both require seeing into the future.

[Garry Kasparov, World Chess Champion 1985-2000]

This book is the result of a four-year PhD research project carried out in Delft, the Netherlands. As the reader has probably noticed, the doctoral research that I am presenting in this book revolves around three key concepts: polycentricity, performance, and planning. These concepts will be developed in the context of Barcelona, Catalonia, a small land of 32,000 square kilometers located on the European continent.

As in a chess match, all research begins with a series of questions. The three main questions in this book, as the reader will see, are derived from wondering about the multiple relationships among the urban structure of metropolitan areas (polycentricity), their performance (considering each area's economic, social, and environmental aspects), and how these metropolitan areas are planned through the elaboration of a spatial plan (planning). This book takes an analytical approach to this triple Ps. In other words, I break the links among polycentricity, performance, and planning into smaller pieces (e.g., polycentricity and performance) to render their examination more feasible. Therefore, I first develop both a policy/discourse analysis and empirical models to examine polycentricity both in policy (spatial plans) and in research (evidence). Second, I develop additional models to estimate the link between polycentricity and the performance of metropolitan areas. Third, I return to the relationship between polycentricity and planning to bring polycentricity's estimated effects on metropolitan performance to architects, planners, and policymakers alike in an evidence-informed manner.

Accordingly, the background idea of this book is to call into question the need for greater symbiosis between research and policy within the field of spatial planning and urban and regional studies to improve both the feasibility and the effectiveness of spatial plans. This idea primarily originates in a constructive criticism of the spatial planning training that I received while pursuing my 6-year Bachelor of Architecture. What I learned in the spatial planning field provided me with a high capacity to raise the appropriate questions to develop a territorial project based on reflection through a *drawn* representation of that territory while simultaneously addressing various territorial scales. However, the answers to these questions would only come from an extensive theoretical body of knowledge relating to urban form and territorial plans, in which the example of growth via *Eixample* (*broadening*, a grid pattern of development), the territorial model of *ciutat de ciutats* (city of cities) and Copenhagen's 1947 Finger Plan featured in the territorial project in a very suggestive way. It is here, in the methodological approach to obtaining answers to the questions raised, where I believed that we architects can improve the tools used to develop a spatial plan. Is it possible to gain additional knowledge, based on empirical evidence, from which cause and effect can be determined?

All of my research not only involves personal travel (made with great effort to carry out independent research) but also requires external support so as to make that travel more enjoyable. Over the past four years, I have had the pleasure of receiving support from many people in various situations and roles. This preface cannot end without a word of thanks to all of them (albeit more briefly than they deserve) because their contribution has been more than vital to developing this doctoral thesis. Therefore, I feel I owe an unpaid debt of gratitude to the following people:

I thank Wil Zonneveld and Evert Meijers, my promoter and co-promoter, for providing me the opportunity to perform a PhD research project at TU Delft. Moreover, I thank them for their continuous dedication, useful comments and excellent coaching that helped me to remain on track with my dissertation and to manage my frequently excessive enthusiasm for achieving more than what would have been possible during four years of research.

I thank all of my colleagues in the Urban and Regional Development section of the OTB Department for Built Environment Research (Kees, Evert, Marloes, Jan Jacob, Erik, Dominic, Bas, Marlojein, Sjoerd, Christa, Dorina, Dena, Paul, and so on) for their hospitality and kindness, which made me feel at home during my time in Delft. A special mention to you, Arie Romein, for sharing your passion for Feyenoord with me and inviting me, more than once, to enjoy the show firsthand at the football stadium. I would also like to extend my gratitude to my office mates (before my relocation to the BK building), Rob Konings, Eikki Kreutzberger and Andreas Faludi, for their short but rewarding talks during working sessions (you made them shorter) and the articles (especially you, Andreas) that you recommended I should read.

I shared space with PhD colleagues (André, Bo Wang, Paul, Dena and Igor, among others) at BG.West.550, BK, beginning in January of this year. Thank you for the working environment that you created, for the casual outings to Bouwpub and for inviting me to play football with you. André, I hope to be able to read your masterpiece soon!

I thank the Universitat Politècnica de Catalunya for the training and assistance that I received and for the most endearing memories with my travel companions during my time in Barcelona. I also thank Maria Montaner, who represents the interadministrative consortium of the Metropolitan Transportation Authority of Barcelona; Ernest Ruiz, who represents the public administration body of the Barcelona Metropolitan Area; and the Statistical Institute of Catalonia and the Department of Territory and Sustainability of the Catalan Government, which efficiently provided me with most of the databases required to develop my doctoral thesis.

I also thank all of my friends who came to visit in Delft and encouraged me to carry on. Thank you, Alex, Arnau and Roger, for the long weekend when you visited and the frequent Skype calls, but especially for the strong friendship that had bonded us since we began school at Garbí. Pablo, David, Carlos and Àngel, thank you for our Skype chats, for the planned visits to Delft and the meetings half-way in Amsterdam. Keeping in touch with you despite our geographical distance to discuss our experiences 'as architects' abroad, in Chester, Beijing or Bamberg, helped me switch off when I needed to do so.

Finally, I wish to thank my family—my brother and parents. Thank you, Oriol, for challenging me every time we saw each other, whether in Barcelona or Menorca, and when you used to come to Delft without notice (well, one hour's notice, to be precise...), when you would say to me: "Jaume, when are you finishing? It's about time, isn't it?" Surely, this was the extra motivation I needed! Dad and Mum, words cannot express what you have done for me.

Jaume Masip-Tresserra
Delft, December 2015

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Summary

Problem statement

More than half of the world's population currently lives in urban settlements, a proportion that is expected to increase to more than 65 percent by 2050 (UN, 2014). The larger agglomerations are a complex spatial configuration of places and flows that are polycentric by nature, or at least they demonstrate a certain development of a multi-center structure. Recently, the focus on agglomerations' polycentric structure has attracted a great deal of attention from both researchers and policymakers, who must manage the economic, social, and environmental challenges that the population of these metropolitan agglomerations will experience in the coming decades.

In research, a considerable portion of the study of polycentric agglomerations has focused on the conceptualization of polycentricity and the empirical analysis of its economic, social, and environmental dis(advantages). Although academics have made a strong effort both to clarify the concept of polycentricity and to empirically explore its dis(advantages)—see, e.g., the special issues of journals such as *European Planning Studies* (1998; 2015), *Urban Studies* (2001) and *Regional Studies* (2014)—two major issues remain in the literature.

First, various approaches to polycentricity co-exist without a high level of integration. One approach refers to polycentricity on the intra-urban (Davoudi, 2003) or intra-metropolitan scale (Brezzi and Veneri, 2015; Limtanakool, 2006), whereas another refers to polycentricity on the inter-urban (Davoudi, 2003) or regional scale (Brezzi and Veneri, 2015; Veneri and Burgalassi, 2012). Moreover, when these approaches are integrated, they are often conflated, at least to an extent (Van Meeteren et al., 2015). Second, empirical examinations of the economic, social and environmental advantages of polycentricity have not yet led to conclusive findings (see, e.g., Burger, 2011; Lee, 2006a; Meijers, 2007a).

In the policy realm, polycentric development appears to be the main hallmark of spatial plans for metropolitan areas worldwide. Indeed, more than 75 percent of recent spatial plans developed for large metropolitan areas in OECD countries consider polycentric development as the best strategy for managing urban development. Some of the key policy objectives that polycentric development is expected to fulfill include offering an economical, efficient transportation system and a sustainable environment, along with extending access to education, jobs, amenities, and decent housing to a large number of people. Policy experts' current interest in polycentricity is rooted in the early 1990s, when after two decades of focusing on local urban development projects and land-use regulations, planning practice refocused its attention on producing strategic frameworks and visions for territorial development in cities and metropolitan regions, strongly emphasizing their relationship with *sustainable development* (Albrechts et al., 2003). Polycentric development therefore re-entered planning practice as a bridging concept between *sustainable development* (broadly interpreted as fulfilling economic, social, and environmental objectives) and territorial development. However, the understanding of polycentric development in current planning policies appears largely disconnected from the ongoing polycentricity debate in research.

This lack of connection between the understanding of polycentricity in research (evidence) and in policy (spatial plans) becomes apparent when considering the issue of how polycentric development can be conceptualized in spatial plans and how the assumed benefits of polycentricity can be realized in planning practice. This issue is of great importance to facilitating a more evidence-informed planning in which polycentricity appears as a bridge-building tool between research (evidence) and policy (spatial plans) with the aim of improving the feasibility and effectiveness of spatial plans' economic, social, and environmental objectives.

It is necessary to conduct a further exploration of the three aforementioned major issues related to (1) the conceptualization of polycentricity, (2) the empirical analysis of the dis(advantages) of polycentricity, and (3) how to interpret the relationship between polycentricity in research and polycentricity in policy. That is the key motivation for this thesis: to link the knowledge of polycentric constellations and their economic, social, and environmental effects to planning practice and policy in metropolitan areas.

General aims and questions

The overarching research goal of this dissertation is to contribute to the debate on polycentricity in the three interrelated issues mentioned above. First, it aims to renew the conceptualization of polycentricity by bringing together two distinct literatures, namely, the literature on intra-urban polycentricity and the literature on inter-urban polycentricity. Second, it aims to empirically substantiate the relationship between polycentricity and performance in metropolitan areas. Third, it aims to understand how the makers of spatial plans have addressed polycentric development and how the assumed benefits of polycentricity can be realized in planning practice. To accomplish these goals, this thesis addresses three general research questions:

1. How has the conceptualization of polycentric development in spatial plans evolved over time, and what can be learned from this evolution?
2. How has polycentricity been conceptualized in research, and how can it inform planning practice?
3. To what extent does polycentricity foster better performance in a metropolitan area, and how can its effects be realized in planning practice?

Single case study: the Barcelona metropolitan region

The case study of this thesis is the Barcelona metropolitan region. With approximately 5 million people, the Barcelona metropolitan region is the primary urban agglomeration of Catalonia, an autonomous region of 7.5 million inhabitants that is located in Spain. The study on the multiple links among polycentricity, performance, and planning within the Barcelona metropolitan region yields learning potential for other metropolitan regions because there exists, for example, a strong historical planning tradition in Catalonia and ideas on polycentric development have been around for many decades. This enables the study of transition patterns in the conceptualization of polycentric development in planning over time. Even the most recent plan for the Barcelona metropolitan region, the 2010 Barcelona Metropolitan Territorial Plan, is influenced by a planning vision of polycentricity that was coined by the 1966 Director Scheme of the Barcelona Metropolitan Area. The latter plan was one of the first to break with the then-popular concentric model of green belts and satellite cities and to propose networked, polycentric spatial configurations to resolve the pressure of urbanization on metropolitan regions' central cities.

Research methods

This dissertation employs several research methods to explore how the multiple relationships among polycentricity, performance, and planning manifest themselves in the Barcelona metropolitan region. The methods used include qualitative methods such as policy/discourse analysis to answer the first general research question about how the conceptualization of polycentric development in spatial plans has evolved over time and what can be learned from this evolution. Additionally, this thesis employs quantitative methods such as descriptive statistics, correspondence analysis, simple regression models, and advanced regression models (in which both spatial autocorrelation and endogeneity issues are controlled to avoid biased estimation results) to address the second general question, which refers to how polycentricity has been identified and measured in research and how this identification and measurement of polycentricity can inform planning practice. Finally, this research uses advanced statistical methods to answer the third general question of the extent to which polycentricity fosters better performance in a metropolitan area and how the effects of polycentricity can be realized in planning practice. These methods include both multilevel multinomial logit models and multilevel structural equation models. Because of the use of these models, this dissertation can explain the estimated effects of the link between polycentricity and performance to architects, planners, and policymakers in an evidence-informed form.

Contributions to the literature

In fulfilling the threefold goal of this thesis to contribute to the debate on polycentricity with respect to the three interrelated issues mentioned above, this thesis has also made two other main contributions.

First, this dissertation has proposed a novel methodology to identify centers in metropolitan areas by considering the different pathways through which centers, and thus a polycentric configuration, may emerge, namely, the decentralization and the incorporation-fusion trajectories. This required the integration of two quite separate literatures. What also added to the novelty of this methodology was the introduction of the concept of 'agglomeration shadows', which has received little attention in the literature, when evaluating this identification method against its fit with the theoretical and empirical (polycentric) models adopted in the economics literature. More specifically, this thesis has also proposed a new, theory-informed conceptualization of centers as not only places with the highest level of agglomeration economies in a metropolitan area but also places that cast the most wide-ranging (spatially), powerful agglomeration shadows over their surroundings. Therefore, the center's concept proposed in this dissertation is not exclusively static; instead, it is also placed into a dynamic perspective: a center in a metropolitan area must cast an 'agglomeration shadow' (*growth shadow effects*) over its surrounding areas, meaning that the number of firms and the amount of urban development (growth) in areas near a center will be limited because of fierce competition effects.

Second, this thesis has proposed a conceptual framework for exploring the link between polycentricity (on the intra-urban scale) and metropolitan performance aimed at enabling broad testing of the effects of polycentricity. Building upon the relationship between theories of agglomeration and polycentricity in the literature, this thesis argues that the consideration of three distinct dimensions of a polycentric spatial structure that play a role in the development of agglomeration economies in a metropolitan area—namely, (1) the size of centers, (2) the (geographic) proximity to centers, and (3) the aggregate size of centers through their integration—allows scholars to arrive at broader conclusions about the effects of polycentricity. The translation of these three dimensions of a polycentric metropolitan structure into a more comprehensive, systematic empirical framework has required an examination of the effects (1) of being located in or oriented toward centers, (2) of being located close to centers, and (3) of interaction patterns among centers.

Conclusions

Below are the main conclusions regarding the three general research questions.

How has the conceptualization of polycentric development in spatial plans evolved over time, and what can be learned from this evolution?

Envisioning polycentric development in spatial plans has become a hallmark of planning practice in Catalonia. The first vision of polycentric development appeared in the 1930s as a response to the debate about the urban-rural opposition between Barcelona (city) and Catalonia (countryside) that resulted from increasing demands to address the (negative) challenges posed by cities' industrialization. Since then, the vision of polycentric development in spatial plans evolved, showing two transitions in its conceptualization in successive plans. The first transition was that although polycentricity was first conceptualized as a decentralization strategy aimed at restricting Barcelona's growth, it later changed into a territorial model to organize and canalize future urban development building on the urban dynamics themselves. The second transition involved the addition of a network perception to the vision on polycentric development. This network perception on polycentricity made a definitive contribution to overcoming the antagonism between Barcelona and Catalonia because it integrated the capital city of Barcelona into a polycentric territorial model for the entire territory of Catalonia.

The applications of polycentric development in various spatial plans in Catalonia also exposed some shortcomings stemming from spatial plans' prescriptive or normative approaches to defining polycentric development in which the empirical evidence related to existing territory was overlooked. However, the simultaneous consideration of all of the applications of polycentric development in spatial plans—and therefore, when the role played by factors other than evidence, such as interests and institutional policy traditions can be better disentangled—noted that some shortcomings in the definition of a polycentric development strategy can be explained by the fact that to a certain extent, plans are indeed politicized. This posed the challenge of building an understanding of polycentric development that was more closely connected to the ongoing academic debate on polycentricity and thus, a call for a more evidence-informed planning based on an improved knowledge of polycentricity, primarily respect for its conceptualization (identification and measurement) and effects on the economic, social, and environmental performance of metropolitan areas. Public and private actors influencing policy, for example, through their ideology or their own interests, would occupy a crucial role in the implementation of this understanding of polycentric development, based on considering (or not) the policy guidelines/recommendations that resulted from empirical evidence and aimed to improve the effectiveness and feasibility of spatial plans.

How has polycentricity been conceptualized in research, and how can it inform planning practice?

A better integration between the literatures on the conceptualization of polycentricity potentially informs spatial plans about the effectiveness and feasibility of polycentric development strategies. This integration revealed which method (empirical or non-empirical) of identifying centers most accurately defines the polycentric model in the Barcelona metropolitan region, which is an essential step in empirically substantiating the link between polycentricity and performance in a metropolitan area because differences in the identification of centers could lead to different conclusions on the understanding of the costs and benefits of a polycentric metropolitan structure. The main advantage of the novel method of identifying centers that is proposed and tested here is that it considers the various pathways through which centers may emerge, namely, the decentralization and the incorporation-fusion trajectories. This method was better able to identify as centers those cities that have the highest level of agglomeration economies and cast the most severe agglomeration shadows over their surroundings.

In addition, the incorporation of the functional and morphological dimensions of polycentricity—as traditionally coined by the inter-urban polycentricity literature—into the measurement of the degree of polycentricity on the intra-urban scale has contributed to building more sound arguments either for or against supporting a polycentric development strategy in a metropolitan area. Additionally, it has provided planners with valuable insights into not only how to address issues related to the understanding, governance implications, and expectations of polycentric development but also how to monitor the implementation of a polycentric development strategy.

To what extent does polycentricity foster better performance in a metropolitan area, and how can its effects be realized in planning practice?

A polycentric metropolitan structure exerts a considerable influence—both active and passive—on enhancing performance in a metropolitan area through individuals' travel behavior. The effects of polycentricity—i.e., (1) of being located in or oriented toward centers, (2) of being located close to centers, and (3) of interaction patterns among centers—appear to be generally larger than the effects of individual-specific characteristics (i.e., sociodemographic characteristics and travel-related attitudes) and built environment attributes with respect to encouraging people to use more intensely sustainable mode choices (public transit and non-motorized modes) and reducing travel behavior externalities (i.e., trip distance, trip time, and transportation-related CO_2 emissions). More specifically, the most important dimension of a polycentric metropolitan structure in fostering a more sustainable mobility pattern is generally the type of interaction, followed by the type of city, which in turn is more important than the distance to centers.

Based on these effects, polycentric development fosters better performance in the Barcelona metropolitan region because it has influenced individuals' travel behavior through three different dimensions. First, people living in centers or doing their daily activities in these centers use more public transit or slow modes, and their trips are shorter, take less time, and cause less transportation-related CO_2 emissions than if they do not live in centers or are not carrying out their activities in these centers. Second, people living close to centers exhibit a more sustainable pattern of travel behavior than those living further away. Third, people traveling among centers are more likely to use public transportation, to experience shorter-length or -duration trips and to make greater reductions in the environmental impact of their travel than people traveling among peripheral areas. In short, agglomeration benefits in a polycentric metropolitan region explain these three aforementioned findings. Therefore, the translation of the benefits of polycentricity into planning policies requires the simultaneous consideration of (1) the size of centers, (2) the size of and proximity to centers, and (3) the size of and interaction among centers.

Evidence-informed guidelines for planning policies

The estimated effects of polycentricity on individuals' travel behavior have led to a set of policy recommendations on urban and transportation developments that will enhance the performance of the Barcelona metropolitan region. These policies inform the plans' makers about how the benefits of polycentricity can be realized in planning practice and therefore, provide them with an improved understanding of polycentric development to more effectively fulfill spatial plans' economic, social, and environmental objectives.

Essentially, the translation of the benefits of polycentricity into evidence-informed guidelines for planning policies has required the consideration of the various dimensions of a polycentric spatial structure that play a role in the development of agglomeration benefits in a metropolitan area:

(1) the size of centers, (2) the proximity to centers, and (3) the aggregate size of centers through their integration. Seven policy recommendations have been elaborated to improve the effectiveness of the planning objectives of the 2010 Barcelona Metropolitan Territorial Plan in terms of individuals' travel costs and the environmental impact of travel.

Aggregate size of centers through their integration

1 Support new, more efficient public transportation networks among centers to allow those centers to better exploit their aggregate urban size, leading to a greater development of agglomeration economies.

2 Enhance the complementarity among centers on the metropolitan scale in terms of economic sectors, occupations, and urban functions through promoting compact-city/transit-oriented development.

3 Support new, more efficient public transportation networks between centers and their neighboring areas to stimulate interactions toward centers and increase nearby residents' access to the agglomeration benefits of centers that are integrated with their nearest center.

4 Support new, more efficient road networks among secondary centers to mitigate congestion along the radial transportation axes oriented toward the central city of Barcelona.

Size of centers

5 Promote compact-city/transit-oriented development in existing centers (central city and secondary centers) to encourage more residents of centers to access their agglomeration benefits.

Proximity to centers

6 Promote compact-city/transit-oriented development in larger places near centers to allow more residents of these centers' neighboring areas to benefit from their proximity to the agglomeration benefits of one or more centers.

7 Limit growth in areas located further away from centers both to mitigate (as much as possible) the high travel costs (trip distance and time) incurred by the residents of these peripheral areas and to decrease the transportation-related CO_2 emissions that they cause.

Agenda for research and policy

Despite providing new insights and conceptual and empirical frameworks to analyze the multiple relationships between polycentricity, performance, and planning in metropolitan regions, further research is needed to address a range of challenges and research gaps that this dissertation could not cover in their entirety. These challenges and research gaps refer both to the Barcelona metropolitan region case and to more general advances that are needed in the reciprocal relationships among polycentricity, performance, and planning.

The focus on individuals' travel behavior in this dissertation's empirical analyses needs to be extended to achieve broader conclusions about the effects of polycentricity on the performance of the Barcelona metropolitan region. Moreover, this dissertation's empirical analyses must be extended to elaborate more comprehensive evidence-informed guidelines for planning policies that address all of the planning objectives of the 2010 Barcelona Metropolitan Territorial Plan. Two additional research perspectives can be distinguished to address these demands. First, the object of analysis could be extended from people to firms and their spatial behavior. Second, a wider range of externalities could be considered. It would be particularly interesting to conduct additional research into the link between polycentricity and other indicators of performance such as labor productivity, unemployment, housing and land prices, income per capita, household-related CO_2 emissions, and land consumption.

The type of exploration performed in this thesis, a single case study, calls for further research into whether its findings can be corroborated in other metropolitan areas. Many perspectives on new research can be distinguished, but the following two are probably the most important. The first perspective would involve carrying out a multi-case study research aimed at examining the effects of polycentricity on metropolitan performance (using the indicators of performance mentioned above) by considering—and extending, if possible—the conceptual framework of this thesis mentioned above. The second perspective would involve conducting a multi-case study research aimed at testing the novel method of identifying centers proposed in this thesis against other identification methods.

Samenvatting

Probleemstelling

Meer dan de helft van de wereldbevolking woont nu in stedelijke nederzettingen, een aandeel dat in 2050 naar verwachting zal zijn toegenomen tot meer dan 65 procent (UN, 2014). De grotere agglomeraties vormen complexe ruimtelijke configuraties van plaatsen en stromen, die naar hun aard polycentrisch zijn of althans een zekere mate van ontwikkeling naar een multicentrische structuur vertonen. De laatste tijd is er veel aandacht voor de polycentrische structuur van agglomeraties, niet alleen bij onderzoekers maar ook onder beleidsmakers, die voor de opgave staan om de economische, sociale en milieutechnische uitdagingen te beheersen waarmee de bevolking van deze metropoolagglomeraties de komende decennia geconfronteerd zal worden.

In het wetenschappelijk onderzoek heeft een aanzienlijk deel van de bestudering van polycentrische agglomeraties zich gericht op de conceptualisatie van polycentriciteit en de empirische analyse van de economische, sociale en milieutechnische voor- en nadelen ervan. Hoewel onderzoekers zich zeer hebben ingespannen om het verschijnsel polycentriciteit te verklaren en de voor- en nadelen ervan empirisch te verkennen—zie bijvoorbeeld de speciale nummers van wetenschappelijke tijdschriften als *European Planning Studies* (1998; 2015), *Urban Studies* (2001) en *Regional Studies* (2014)—blijven er in de literatuur twee grote vraagstukken over.

Ten eerste bestaan er verschillende benaderingen van polycentriciteit naast elkaar, zonder veel integratie. Eén benadering hanteert polycentriciteit op intra-urbane (Davoudi, 2003) of intra-metropolitane schaal (Brezzi and Veneri, 2015; Limtanakool, 2006), terwijl in een andere benadering naar polycentriciteit wordt verwezen op inter-urbane (Davoudi, 2003) of regionale schaal (Brezzi and Veneri, 2015; Veneri and Burgalassi, 2012). Wanneer deze benaderingen worden geïntegreerd, worden de betekenissen vaak tot op zekere hoogte door elkaar gebruikt (Van Meeteren et al., 2015). Ten tweede heeft empirisch onderzoek naar de economische, sociale en milieutechnische voordelen van polycentriciteit nog niet tot definitieve conclusies geleid (zie bijvoorbeeld Burger, 2011; Lee, 2006a; Meijers, 2007a).

In het politieke landschap lijkt de polycentrische ontwikkeling wereldwijd het hoofdkenmerk van ruimtelijke plannen voor metropoolgebieden te zijn. In meer dan 75 procent van de recent ontwikkelde ruimtelijke plannen voor grote metropoolgebieden in OESO-landen wordt een polycentrische ontwikkeling zelfs als de beste strategie voor de beheersing van stadsontwikkeling beschouwd. Enkele van de belangrijkste beleidsdoelstellingen die men met de polycentrische ontwikkeling verwacht te realiseren, zijn een economisch en efficiënt transportsysteem en een duurzaam milieu, naast betere toegang tot onderwijs, werkgelegenheid, voorzieningen en goede huisvesting voor velen. De huidige belangstelling van beleidsdeskundigen voor polycentriciteit gaat terug tot de vroege jaren '90 van de twintigste eeuw, toen in de planningspraktijk na twee decennia nadruk op lokale stadsontwikkelingsprojecten en bestemmingsplannen weer meer focus werd gelegd op de ontwikkeling van strategische kaders voor en visies op de territoriale ontwikkelingen in steden en metropoolregio's, met veel nadruk op de relatie met duurzame ontwikkeling (Albrechts et al., 2003). De polycentrische ontwikkeling maakte derhalve haar rentree in de planningspraktijk als een concept dat een brug moest slaan tussen duurzame ontwikkeling (ruim opgevat als vervulling van economische, sociale en milieutechnische doelstellingen) en territoriale ontwikkeling. De opvatting van polycentrische ontwikkeling in het huidige planningsbeleid lijkt grotendeels los te staan van het actuele polycentriciteitsdebat in de wetenschappelijke literatuur.

Dit gebrek aan verbinding tussen de opvattingen van polycentriciteit in het onderzoek (bewijs) en in het beleid (ruimtelijke plannen) wordt duidelijk wanneer we ingaan op de vraag hoe polycentrische ontwikkeling kan worden geconceptualiseerd in ruimtelijke plannen en hoe de veronderstelde voordelen van polycentriciteit in de praktijk kunnen worden gerealiseerd. Deze vraag is van groot belang om een meer *evidence-informed* planning mogelijk te maken, waarin polycentriciteit optreedt als overbruggend element tussen onderzoek (bewijs) en beleid (ruimtelijke plannen) met als doel de haalbaarheid en effectiviteit van de economische, sociale en milieutechnische doelstellingen van ruimtelijke plannen te vergroten.

Er moet nader onderzoek worden gedaan naar de drie bovengenoemde vraagstukken met betrekking tot (1) de conceptualisatie van polycentriciteit, (2) de empirische analyse van de voor- en nadelen van polycentriciteit en (3) de interpretatie van de relatie tussen polycentriciteit in het onderzoek en polycentriciteit in het beleid. De belangrijkste motivatie voor deze dissertatie is de wens om een verbinding te leggen tussen de kennis van polycentrische constellaties en hun economische, sociale en milieutechnische effecten op de praktijk en het beleid van de ruimtelijke planning in metropoolgebieden.

Algemene onderzoeksdoelen en -vragen

Het overkoepelende onderzoeksdoel van deze dissertatie is een bijdrage te leveren aan het debat over polycentriciteit in verband met de drie bovengenoemde, met elkaar verband houdende vraagstukken. Ten eerste wordt beoogd de conceptualisatie van polycentriciteit te vernieuwen door twee duidelijk te onderscheiden vormen van literatuur samen te brengen, te weten de literatuur over intra-urbane polycentriciteit en de literatuur over inter-urbane polycentriciteit. Ten tweede wordt gestreefd naar empirische onderbouwing van de relatie tussen polycentriciteit en *performance* in metropoolgebieden. Ten derde wordt getracht te begrijpen hoe de opstellers van ruimtelijke plannen zijn omgegaan met polycentrische ontwikkeling en hoe de veronderstelde voordelen van polycentriciteit in de planningspraktijk kunnen worden gerealiseerd. Teneinde deze drie doelen te bereiken, wordt in deze dissertatie antwoord gezocht op drie onderzoeksvragen:

1. Hoe is de conceptualisatie van polycentrische ontwikkeling in ruimtelijke plannen in de loop van de tijd veranderd en wat kan van deze verandering worden geleerd?
2. Hoe is polycentriciteit geconceptualiseerd in het onderzoek, en hoe is dit te integreren in de planningspraktijk?
3. In hoeverre is polycentriciteit bevorderlijk voor een betere *performance* in een metropoolgebied, en hoe kunnen de effecten ervan in de planningspraktijk worden gerealiseerd?

Eén casestudy: metropoolregio Barcelona

De casestudy van deze dissertatie betreft de metropoolregio Barcelona. Met een bevolking van circa 5 miljoen is de metropoolregio Barcelona de grootste stedelijke agglomeratie van Catalonië, een autonome regio van Spanje met 7,5 miljoen inwoners. Bestudering van de vele relaties tussen polycentriciteit, *performance* en planning binnen de metropoolregio Barcelona levert leermogelijkheden op voor andere metropoolregio's, bijvoorbeeld omdat er in Catalonië een sterke historische traditie van planning bestaat en er al vele tientallen jaren wordt nagedacht over polycentrische ontwikkeling. Hierdoor is het mogelijk veranderingspatronen in de conceptualisatie van polycentrische ontwikkeling in de loop van de tijd te bestuderen. Zelfs het meest recente ruimtelijke plan voor de regio, het 'Barcelona Metropolitan Territorial Plan' uit 2010, is beïnvloed door een visie op polycentriciteit die voor het eerst werd geformuleerd in het masterplan voor het metropoolgebied

Barcelona uit 1966. Het laatstgenoemde plan was een van de eerste waarin werd gebroken met het toentertijd populaire concentrische model van groene gordels en satellietsteden en waarin een netwerk van polycentrische ruimtelijke configuraties werd voorgesteld om de urbanisatiedruk op de centrale steden in de metropoolregio te verlichten.

Onderzoeksmethoden

Voor deze dissertatie zijn verschillende onderzoeksmethoden toegepast om na te gaan hoe de vele relaties tussen polycentriciteit, *performance* en planning zich manifesteren in de metropoolregio Barcelona. Daartoe behoren kwalitatieve methoden, zoals beleids- en discoursanalyse om antwoord te geven op de eerste algemene onderzoeksvraag over de wijze waarop de conceptualisatie van polycentrische ontwikkeling in ruimtelijke plannen in de loop van de tijd veranderd is en wat daarvan kan worden geleerd. Daarnaast zijn kwantitatieve methoden gebruikt, zoals beschrijvende statistiek, correspondentieanalyse, eenvoudige regressiemodellen en geavanceerde regressiemodellen (met controle op ruimtelijke autocorrelatie en endogeniteitskwesties ter vermijding van vertekende uitkomsten), om de tweede algemene onderzoeksvraag te beantwoorden: hoe polycentriciteit bij onderzoek wordt geïdentificeerd en gemeten en hoe deze identificatie en meting van polycentriciteit kan worden geïntegreerd in de planningspraktijk. Ten slotte is in dit onderzoek gebruikgemaakt van geavanceerde statistische methoden om de derde algemene onderzoeksvraag te beantwoorden, namelijk in hoeverre polycentriciteit bevorderlijk is voor een betere *performance* in een metropoolgebied en hoe de effecten ervan in de planningspraktijk kunnen worden gerealiseerd. Deze methoden omvatten zowel multi-level multinomiale logistische modellen als multi-level structurele-vergelijkingsmodellen. Dankzij het gebruik van deze modellen kunnen in deze dissertatie de geschatte effecten van het verband tussen polycentriciteit en *performance* in *evidence-informed* vorm worden verklaard voor architecten, planners en beleidsmakers.

Bijdragen aan de literatuur

Door in het kader van haar drieledige doelstelling bij te dragen aan het debat over polycentriciteit ten aanzien van de drie bovengenoemde onderling samenhangende vraagstukken, levert deze dissertatie nog twee andere belangrijke bijdragen.

Allereerst wordt in deze dissertatie een nieuwe methodologie voorgesteld voor de identificatie van centra in metropoolgebieden door de verschillende routes te beschouwen waarlangs centra, en derhalve ook polycentrische configuraties, kunnen ontstaan, namelijk de route van de decentralisatie en die van de versmelting. Dit vereiste de integratie van twee heel verschillende literatuurstromingen. Wat tevens bijdraagt aan de nieuwheid van deze methodologie is de introductie van het begrip *agglomeration shadows*, waaraan in de literatuur nog maar weinig aandacht is besteed, bij de beoordeling van de identificatiemethode aan de hand van de theoretische en empirische (polycentrische) modellen die in de economische literatuur gangbaar zijn. Meer specifiek wordt in deze dissertatie ook een nieuwe, theoretisch verantwoorde conceptualisatie gepresenteerd van centra die niet slechts de plaatsen zijn met de hoogste mate van economisch agglomeratievoordeel in een metropoolgebied, maar ook de plaatsen die in de agglomeratie de (ruimtelijk) langste schaduw werpen over hun omgeving. Derhalve is het in deze dissertatie voorgestelde centrumconcept niet uitsluitend statisch, maar wordt het ook in een dynamisch perspectief geplaatst: een centrum in een metropoolgebied moet een *agglomeration shadow* (*growth shadow effects*) over de omgeving werpen, dat wil zeggen dat het aantal bedrijven en de stedelijke ontwikkeling (groei) in gebieden nabij het centrum beperkt zullen zijn vanwege hevige concurrentie.

In de tweede plaats wordt in deze dissertatie een conceptueel kader voor onderzoek naar het verband tussen polycentriciteit (op intra-urbane schaal) en *performance* van de metropool voorgesteld, waarmee de effecten van polycentriciteit op brede schaal kunnen worden getest. Op basis van de relatie tussen theorieën over agglomeraties en polycentriciteit in de literatuur, wordt in deze dissertatie aangevoerd dat onderzoekers ruimere conclusies over de effecten van polycentriciteit kunnen trekken wanneer zij rekening houden met de drie onderscheiden dimensies van een polycentrische ruimtelijke structuur die een rol spelen bij de ontwikkeling van economisch agglomeratievoordeel in een metropoolgebied, te weten (1) de omvang van de centra, (2) de (geografische) nabijheid van centra en (3) de geaggregeerde omvang van geïntegreerde centra. Voor de vertaling van deze drie dimensies van een polycentrische metropoolstructuur in een meer omvattend, systematisch empirisch kader is onderzoek vereist naar de effecten van (1) het gevestigd zijn in of gericht zijn op centra, (2) het gevestigd zijn nabij centra en (3) patronen van interactie tussen centra.

Conclusies

De belangrijkste conclusies ten aanzien van de drie algemene onderzoeksvragen luiden als volgt.

Hoe is de conceptualisatie van polycentrische ontwikkeling in ruimtelijke plannen in de loop van de tijd veranderd en wat kan van deze verandering worden geleerd?

Een visie op polycentrische ontwikkeling in ruimtelijke plannen is het handelsmerk van de Catalaanse planningspraktijk geworden. De eerste visie op polycentrische ontwikkeling verscheen in de jaren '30 van de twintigste eeuw naar aanleiding van het debat over de tegenstelling tussen Barcelona (stad) en de rest van Catalonië (platteland) dat was voortgekomen uit de toenemende noodzaak om iets te doen aan de (negatieve) uitdagingen als gevolg van de industrialisatie van de stad. Sindsdien is de visie op polycentrische ontwikkeling in ruimtelijke plannen geëvolueerd, met twee veranderingen in de conceptualisatie in opeenvolgende plannen. De eerste verandering hield in dat polycentriciteit, aanvankelijk geconceptualiseerd als decentralisatiestrategie om de groei van Barcelona te beperken, later evolueerde tot een ruimtelijk model om toekomstige stedelijke ontwikkeling te organiseren en te kanaliseren op basis van de stedelijke dynamiek zelf. Bij de tweede verandering werd een netwerkperceptie aan de visie op polycentrische ontwikkeling toegevoegd. Deze netwerkperceptie van polycentriciteit heeft een beslissende bijdrage geleverd aan het overbruggen van de tegenstelling tussen Barcelona en Catalonië omdat hierdoor de hoofdstad Barcelona werd geïntegreerd in een polycentrisch ruimtelijk model voor het hele grondgebied van Catalonië.

De toepassing van polycentrische ontwikkeling in verschillende ruimtelijke plannen in Catalonië heeft ook een aantal tekortkomingen aan het licht gebracht als gevolg van prescriptieve en normatieve definities van polycentrische ontwikkeling in ruimtelijke plannen waarin empirisch bewijs met betrekking tot bestaande gebieden werd genegeerd. Wanneer echter gelijktijdig alle toepassingen van polycentrische ontwikkeling in ruimtelijke plannen worden beschouwd—waarbij de rol van andere factoren dan harde bewijzen, zoals belangen en institutionele beleidstradities, gemakkelijker kan worden geneutraliseerd—valt op dat bepaalde tekortkomingen in de definitie van een polycentrische ontwikkelingsstrategie kunnen worden verklaard door het feit dat de plannen tot op zekere hoogte gepolitiseerd zijn. Dit betekent dat de uitdaging lag in het vormen van inzicht in polycentrische ontwikkeling dat nauwer verbonden was met het actuele academische debat over polycentriciteit en dat daarom moet worden gepleit voor een meer *evidence-informed* planning op basis van betere kennis van polycentriciteit, met primair respect voor de conceptualisatie (identificatie en meting) en de effecten ervan op de economische, sociale en milieutechnische *performance* van metropoolgebieden. Publieke en private partijen die het beleid beïnvloeden, bijvoorbeeld vanuit hun ideologie of hun eigenbelang, zullen een cruciale rol moeten spelen bij de implementatie van dit inzicht in de polycentrische ontwikkeling, gebaseerd op de mate waarin zij al dan niet rekening houden met de beleidsrichtlijnen en aanbevelingen die voortkomen uit het empirische bewijs en gericht zijn op verbetering van de effectiviteit en haalbaarheid van ruimtelijke plannen.

Hoe is polycentriciteit geconceptualiseerd in het onderzoek, en hoe is dit te integreren in de planningspraktijk?

Een betere integratie van de verschillende opvattingen over de conceptualisatie van polycentriciteit in de literatuur kan betekenen dat de effectiviteit en haalbaarheid van polycentrische ontwikkelingsstrategieën in ruimtelijke plannen beter uit de verf komen. Uit deze integratie blijkt welke methode (empirisch of niet empirisch) voor de identificatie van centra tot de beste definitie van het polycentrische model in de metropoolregio Barcelona leidt, wat een essentiële stap is in de empirische onderbouwing van het verband tussen polycentriciteit en *performance* in een metropoolgebied, omdat verschillen in de identificatie van centra kunnen uitmonden in uiteenlopende conclusies over de kosten en baten van een polycentrische metropoolstructuur. Het grootste voordeel van de hier voorgestelde en geteste nieuwe methode om centra te identificeren is dat rekening wordt gehouden met de verschillende routes waarlangs centra kunnen ontstaan, namelijk de route van de decentralisatie en die van de versmelting. Met deze methode kunnen steden met de hoogste mate van economisch agglomeratievoordeel die de grootste *agglomeration shadows* over hun omgeving werpen, beter worden geïdentificeerd als centra.

Daarnaast heeft de opname van de functionele en morfologische dimensies van polycentriciteit—zoals ze van oudsher worden genoemd in de literatuur over inter-urbane polycentriciteit—in de bepaling van de mate van polycentriciteit volgens de intra-urbane schaal, bijgedragen aan de formulering van betere argumenten voor of tegen een polycentrische ontwikkelingsstrategie in een metropoolgebied. Bovendien hebben planners hierdoor waardevolle nieuwe inzichten gekregen, niet alleen met betrekking tot zaken als kennis, bestuurlijke implicaties en verwachtingen van polycentrische ontwikkeling maar ook over het monitoren van de implementatie van een polycentrische ontwikkelingsstrategie.

In hoeverre is polycentriciteit bevorderlijk voor een betere performance in een metropoolgebied, en hoe kunnen de effecten ervan in de planningspraktijk worden gerealiseerd?

Een polycentrische metropoolstructuur oefent via het individuele reisgedrag actief en passief een aanzienlijke invloed uit op de *performance*-verbetering in een metropoolgebied. De effecten van polycentriciteit, dat wil zeggen van (1) het gevestigd zijn in of gericht zijn op centra, (2) het gevestigd zijn nabij centra en (3) patronen van interactie tussen centra, blijken in het algemeen groter dan de effecten van individuele eigenschappen (sociodemografische kenmerken en reisattitudes) en kenmerken van de gebouwde omgeving als het erom gaat mensen aan te moedigen duurzamere transportkeuzes te maken (openbaar vervoer en niet-gemotoriseerde vormen van vervoer) en de bijwerkingen van het reisgedrag (reisafstand, reistijd en CO_2-uitstoot) te verminderen. Meer specifiek is de belangrijkste dimensie van een polycentrische metropoolstructuur bij het stimuleren van een duurzamer mobiliteitspatroon in het algemeen het type interactie, gevolgd door het type stad, dat op zijn beurt weer belangrijker is dan de afstand tot het centrum.

Op grond van deze effecten leidt de polycentrische ontwikkeling tot een betere *performance* in de metropoolregio Barcelona doordat zij het individuele reisgedrag langs drie verschillende dimensies beïnvloedt. Ten eerste maken mensen die in de centra wonen of daar hun dagelijkse activiteiten hebben, meer gebruik van openbaar of niet-gemotoriseerd vervoer, terwijl hun reizen korter zijn, minder tijd kosten en minder transportgerelateerde CO_2-uitstoot veroorzaken dan als ze niet in centra wonen of daar hun dagelijkse activiteiten uitoefenen. Ten tweede vertonen mensen die in de nabijheid van centra wonen, een duurzamer reispatroon dan degenen die verder weg wonen. Ten derde gebruiken mensen die tussen centra reizen vaker het openbaar vervoer, maken ze kortere en korter durende reizen en verminderen ze het milieueffect van hun reizen verder dan mensen die tussen perifere gebieden reizen. Om kort te gaan worden de drie bovengenoemde bevindingen verklaard door de agglomeratievoordelen in een polycentrische metropoolregio. Daarom moet bij de vertaling van de voordelen van polycentriciteit in het planningsbeleid gelijktijdig rekening worden gehouden met (1) de omvang van de centra, (2) de omvang en nabijheid van de centra en (3) de omvang van en interactie tussen de centra.

Evidence-informed richtlijnen voor het planningsbeleid

De berekende effecten van polycentriciteit op het individuele reisgedrag hebben geleid tot een aantal beleidsaanbevelingen met betrekking tot stads- en vervoersontwikkelingen die de *performance* van de metropoolregio Barcelona zullen verbeteren. Met deze beleidsaanbevelingen weten de plannenmakers hoe de voordelen van polycentriciteit in de planningspraktijk kunnen worden gerealiseerd en krijgen ze dus een beter inzicht in de manier waarop polycentrische ontwikkeling de economische, sociale en milieutechnische doelstellingen van ruimtelijke plannen effectiever kan helpen realiseren.

In essentie moet bij de vertaling van de voordelen van polycentriciteit in *evidence-informed* richtlijnen voor het planningsbeleid rekening worden gehouden met de verschillende dimensies van een polycentrische ruimtelijke structuur die een rol spelen bij de ontwikkeling van agglomeratievoordelen in een metropoolgebied: (1) de omvang van centra, (2) de nabijheid van centra en (3) de geaggregeerde omvang van centra als gevolg van hun integratie. Er zijn zeven beleidsaanbevelingen uitgewerkt ter vergroting van de effectiviteit van de doelstellingen in het 'Barcelona Metropolitan Territorial Plan' uit 2010 in termen van individuele reiskosten en milieueffecten van reizen.

Geaggregeerde omvang van centra als gevolg van hun integratie

1. Steun nieuwe, efficiëntere openbaarvervoernetwerken tussen centra, waardoor die centra hun geaggregeerde stedelijke omvang beter kunnen benutten zodat de economische agglomeratievoordelen zich sterker ontwikkelen.
2. Versterk de complementariteit tussen centra op metropoolniveau in termen van economische sectoren, beroepen en stedelijke functies door de ontwikkeling van de op vervoer gerichte compacte stad te stimuleren.
3. Steun nieuwe, efficiëntere openbaarvervoernetwerken tussen centra en hun omgeving om interacties richting centra te stimuleren en bewoners in de omgeving meer toegang te geven tot de agglomeratievoordelen van centra die zijn geïntegreerd met hun dichtstbijzijnde centrum.
4. Steun nieuwe, efficiëntere wegennetten tussen secundaire centra om de congestie te verminderen op de radiale verkeersassen die zijn gericht op het centrum van de stad Barcelona.

Omvang van centra

5. Stimuleer op vervoer gerichte, compacte stadsontwikkeling in bestaande centra (centrale stad en secundaire centra) om meer centrumbewoners aan te moedigen gebruik te maken van hun agglomeratievoordelen.

Nabijheid van centra

6 Stimuleer op vervoer gerichte, compacte stadsontwikkeling in grotere plaatsen nabij centra om meer bewoners van deze bij centra gelegen gebieden te laten profiteren van de nabijheid van de agglomeratievoordelen van een of meer centra.

7 Beperk de groei in gebieden die verder van centra liggen, zowel om de hoge reiskosten in afstand en tijd voor de bewoners van deze perifere gebieden (zoveel mogelijk) te verlagen als om de door hen veroorzaakte transportgerelateerde CO_2-uitstoot te verminderen.

Onderzoeks- en beleidsagenda

Ondanks de nieuw verworven inzichten en de conceptuele en empirische kaders om de vele relaties tussen polycentriciteit, *performance* en planning in metropoolregio's te analyseren, is nader onderzoek nodig om in te gaan op een aantal uitdagingen en onderzoekslacunes die in deze dissertatie niet in hun geheel kunnen worden behandeld. Deze uitdagingen en onderzoekslacunes betreffen niet alleen de metropoolregio Barcelona maar ook de meer algemene vooruitgang die nodig is in het onderzoek naar de onderlinge relaties tussen polycentriciteit, *performance* en planning.

De nadruk op individueel reisgedrag bij de empirische analyses in deze dissertatie zal moeten worden uitgebreid om bredere conclusies te kunnen trekken over de effecten van polycentriciteit op de *performance* van de metropoolregio Barcelona. Verder moeten de empirische analyses van deze dissertatie worden uitgebreid om meer omvattende *evidence-informed* richtlijnen voor het planningsbeleid uit te werken, die ingaan op alle doelstellingen van het ruimtelijke plan voor de metropoolregio Barcelona uit 2010 ('Barcelona Metropolitan Territorial Plan'). Met het oog op deze vereisten kunnen twee aanvullende onderzoeksperspectieven worden onderscheiden. Ten eerste kan het onderwerp van de analyse worden uitgebreid met bedrijven en hun ruimtelijke gedrag. Ten tweede zou een groter aantal bijwerkingen in aanmerking kunnen worden genomen. Het zou bijzonder interessant zijn om aanvullend onderzoek uit te voeren naar het verband tussen polycentriciteit en andere *performance*-indicatoren zoals arbeidsproductiviteit, werkloosheid, huizen- en grondprijzen, inkomen per hoofd van de bevolking, huishoudelijke CO_2-uitstoot en grondgebruik.

Het type onderzoek dat voor deze dissertatie is verricht, één casestudy, vraagt om nader onderzoek naar de vraag of de bevindingen kunnen worden bevestigd in andere metropoolgebieden. Er zijn vele perspectieven voor nieuw onderzoek te onderscheiden, maar de volgende twee zijn waarschijnlijk de belangrijkste. Het eerste perspectief betekent dat meerdere casestudy's worden uitgevoerd, die zijn gericht op onderzoek naar de effecten van polycentriciteit op de *performance* van de metropool (aan de hand van de bovengenoemde *performance*-indicatoren) door het in deze dissertatie beschreven conceptuele kader in aanmerking te nemen en zo mogelijk uit te breiden. Het tweede perspectief betekent dat meerdere casestudy's worden uitgevoerd, waarin de in deze dissertatie beschreven nieuwe methode voor de identificatie van centra wordt vergeleken met andere identificatiemethoden.

Sumari

Descripció del Problema d'investigació

Més de la meitat de la població mundial resideix actualment en assentaments urbans, una proporció que s'espera que s'incrementi fins a més d'un 65 per cent a l'any 2050 (UN, 2014). Les gran aglomeracions s'entenen avui en dia com una configuració espacial complexa de ciutats i fluxos, de naturalesa policèntrica, o com a mínim, d'una certa estructura multicèntrica en desenvolupament. Recentment, l'estructura policèntrica de les aglomeracions ha atret un gran interès tant dels acadèmics com dels legisladors de política pública, per tal de gestionar els reptes econòmics, socials, i ambientals que la població d'aquestes aglomeracions metropolitanes afrontaran en les properes dècades.

En l'àmbit de la recerca, una part considerable de l'estudi de les aglomeracions policèntriques s'ha centrat en la conceptualització del policentrisme i en l'anàlisi empírica dels seus (des)avantatges econòmics, socials i ambientals. Malgrat els grans esforços realitzats pels acadèmics per clarificar tant el concepte del policentrisme com per explorar empíricament els seus (des)avantatges—vegeu, per exemple, les edicions especials de les revistes *European Planning Studies* (1998; 2015), *Urban Studies* (2001) and *Regional Studies* (2014)—dos problemes importants romanen en la literatura.

En primer lloc, coexisteixen diferents maneres d'abordar el policentrisme i per això hi ha certa fragmentació en la seva conceptualització. Una manera d'abordar-lo fa referència a entendre el policentrisme a l'escala territorial intraurbana (Davoudi, 2003) o intrametropolitana (Brezzi and Veneri, 2015; Limtanakool, 2006), mentre que l'altra aborda el policentrisme a l'escala territorial interurbana (Davoudi, 2003) o regional (Brezzi and Veneri, 2015; Veneri and Burgalassi, 2012). A més, quan s'han intentat integrar aquestes conceptualitzacions, s'ha fet de manera confusa (Van Meeteren et al., 2015). En segon lloc, l'anàlisi empírica dels avantatges econòmics, socials i ambientals del policentrisme no ha conduit encara cap a resultats concloents (vegeu, per exemple, Burger, 2011; Lee, 2006; Meijers, 2007a).

En l'àmbit de la política de planificació territorial, el desenvolupament policèntric apareix com el principal segell dels plans territorials per a les àrees metropolitanes d'arreu del món. De fet, més del 75 per cent dels plans territorials recentment desenvolupats per a les grans àrees metropolitanes en països de l'OCDE consideren el desenvolupament policèntric com la millor estratègia per gestionar el desenvolupament urbà. Alguns dels objectius claus en política de planificació territorial els quals s'espera que el desenvolupament policèntric assoleixi inclouen oferir un sistema de transport econòmic i eficient i un medi ambient sostenible, juntament amb estendre l'accés a l'educació, als llocs de treball, a les funcions urbanes i a un habitatge decent per a un gran nombre de gent. L'interès actual dels experts en política territorial pel policentrisme té origen a principis dels anys 1990, quan després de dues dècades de centrar-se en projectes de desenvolupament urbà local i regulacions d'usos de sòl, la praxi de la planificació territorial va reorientar la seva atenció en la producció de marcs estratègics i visions de desenvolupament territorial per a les ciutats i regions metropolitanes, posant un gran èmfasi en les seves relacions amb el *desenvolupament sostenible* (Albrechts et al., 2003). El desenvolupament policèntric va ressorgir doncs en la praxi de la planificació territorial com un concepte pont entre el *desenvolupament sostenible* (àmpliament interpretat com l'assoliment d'objectius econòmics, socials i ambientals) i el desenvolupament territorial. No obstant, el que s'entén per desenvolupament policèntric en les polítiques actuals de planificació territorial està en gran mesura desconnectat del debat actual sobre policentrisme en l'àmbit acadèmic.

Aquesta manca de connexió entre la visió del policentrisme en el camp de la recerca (evidència empírica) i en el camp de la política pública (plans territorials) es posa de manifest quan es considera el problema de com es pot conceptualitzar el desenvolupament policèntric en els plans territorials i com els suposats beneficis del policentrisme es poden realitzar en la praxi de la planificació territorial. Aquest problema és de gran importància a l'hora de facilitar una planificació territorial més informada per l'evidència empírica, en la qual el policentrisme apareix com una eina per construir el pont d'unió entre la recerca (evidència empírica) i la política pública (plans territorials) amb l'objectiu de millorar la viabilitat i l'eficàcia dels objectius econòmics, socials i ambientals dels plans territorials.

És necessari dur a terme més recerca en els tres grans problemes esmentats, relacionats amb (1) la conceptualització del policentrisme, (2) l'anàlisi empírica dels des(avantatges) del policentrisme, i (3) com es pot entendre la relació entre el policentrisme abordat en l'àmbit acadèmic i el policentrisme abordat en l'àmbit de la política de planificació territorial. Això és la motivació clau per fer aquesta tesi: vincular el coneixement de les constel·lacions policèntriques i els seus efectes econòmics, socials i ambientals per a la praxi i la política de la planificació territorial en les àrees metropolitanes.

Objectius generals i preguntes

L'objectiu general d'aquesta investigació doctoral és contribuir al debat actual del policentrisme en relació amb els tres problemes de investigació interrelacionats esmentats més amunt. En primer lloc, la tesi té l'objectiu de renovar la conceptualització del policentrisme, reunint dos estudis diferents, específicament, la literatura sobre el policentrisme a l'escala intraurbana i la literatura sobre el policentrisme a l'escala interurbana. En segon lloc, la tesi té l'objectiu de corroborar empíricament la relació entre policentrisme i l'*eficiència territorial* (àmpliament interpretada com a rendiment 'performance') en les àrees metropolitanes. En tercer lloc, la tesi té com a objectiu entendre com els autors dels plans territorials han abordat el desenvolupament policèntric i com els suposats beneficis del policentrisme es poden realitzar en la praxi de la planificació territorial. Per tal d'assolir aquests objectius, aquesta tesi aborda tres preguntes de recerca generals:

1 Com ha evolucionat la conceptualització del desenvolupament policèntric en els plans territorials amb el temps, i què es pot aprendre d'aquesta evolució?
2 Com ha estat conceptualitzat el policentrisme en l'àmbit de la recerca, i com pot informar la praxi de la planificació territorial?
3 En quina mesura el policentrisme fomenta una major eficiència territorial en una àrea metropolitana, i com els seus efectes es poden realitzar en la praxi de la planificació territorial?

Cas d'estudi únic: la regió metropolitana de Barcelona

El cas d'estudi d'aquesta tesi és la regió metropolitana de Barcelona. Amb aproximadament 5 milions d'habitants, la regió metropolitana de Barcelona és la principal aglomeració urbana de Catalunya, un territori de 7,5 milions d'habitants localitzat al sud-oest d'Europa. L'estudi dels múltiples vincles entre policentrisme, eficiència territorial, i planificació territorial ('polycentricity', 'performance', i 'planning') en la regió metropolitana de Barcelona produeix un potencial d'aprenentatge per a altres regions metropolitanes perquè existeix, per exemple, una forta tradició històrica de planificació territorial a Catalunya, on les idees sobre el desenvolupament policèntric han existit durant dècades. Això permet l'estudi longitudinal de patrons de transició en la conceptualització del desenvolupament policèntric en la planificació territorial. Fins i tot, el pla territorial més recent per a la regió metropolitana de Barcelona, el Pla Territorial Metropolità de Barcelona del 2010, està influenciat per la visió territorial del policentrisme que va ser adoptada pel Pla Director de l'Àrea Metropolitana de Barcelona del 1966. Aquest últim pla territorial va ésser un dels primers a trencar el model concèntric, llavors popular, d'anells verds i ciutats satèl·lits, i proposar configuracions espacials policèntriques en xarxa per tal de resoldre la pressió de la urbanització en les ciutats centrals de les regions metropolitanes.

Mètodes de recerca

Aquesta tesi doctoral utilitza diversos mètodes de recerca per tal d'explorar com les múltiples relacions entre policentrisme, eficiència territorial i planificació territorial es manifesten en la regió metropolitana de Barcelona. Els mètodes utilitzats inclouen mètodes qualitatius com ara l'anàlisi discursiva per tal de respondre la primera pregunta de recerca general sobre com la conceptualització del desenvolupament policèntric en els plans territorials ha evolucionat amb el temps, i què es pot aprendre d'aquesta evolució. També, aquesta tesi utilitza mètodes quantitatius com estadístiques descriptives, anàlisi de correspondència, models de regressions senzills i models de regressions avançats (en els quals tant els problemes d'autocorrelació espacial i com de causalitat recursiva són considerats per evitar biaixos en els resultats estimats) per tal d'abordar la segona pregunta de recerca general, que fa referència a com el policentrisme ha estat identificat i mesurat en l'àmbit de la recerca, i com aquesta identificació i mesura del policentrisme pot informar la praxi de la planificació territorial. Finalment, aquesta tesi utilitza mètodes estadístics avançats per tal de respondre la tercera pregunta de recerca general sobre en quina mesura el policentrisme fomenta una eficiència territorial més gran en una àrea metropolitana, i com els seus efectes es poden materialitzar en la praxi de la planificació territorial. Aquests mètodes inclouen tant els models logístic multinomial multinivell com els models d'equació estructural multinivell. A partir de l'ús d'aquests models, aquesta tesi doctoral pot explicar els efectes estimats de la relació entre policentrisme i eficiència territorial a arquitectes, urbanistes i legisladors de política pública a manera d'evidència informada.

Contribucions a la literatura

En l'assoliment del triple objectiu d'aquesta tesi per contribuir al debat sobre el policentrisme respecte als tres problemes interrelacionats esmentats anteriorment, aquesta investigació també fa dues contribucions principals més.

En primer lloc, aquesta tesi doctoral ha proposat una nova metodologia per identificar centres en àrees metropolitanes a través de considerar les diferents vies per les quals els centres, i per tant una configuració policèntrica, podrien emergir, específicament, la trajectòria de descentralització i la d'incorporació-fusió. Això ha requerit la integració de dos estudis força dispars. El que també contribueix a la novetat d'aquesta metodologia ha estat la introducció d'un concepte que ha rebut poca atenció en la literatura, en concret, el concepte *d'ombres d'aglomeració*, per tal d'avaluar aquest mètode d'identificació a partir de la seva capacitat d'ajustar els models (policèntrics) teòrics i empírics adoptats per la literatura econòmica. Més específicament, aquesta tesi també ha proposat una nova conceptualització dels centres basada en teoria a partir de definir els centres com no només els llocs amb el nivell més alt d'economies d'aglomeració en una àrea metropolitana, sinó també els llocs que projecten les ombres d'aglomeració de més ample abast (espacialment) i més potents sobre els seus entorns. Per tant, el concepte de centre proposat en aquesta tesi no és exclusivament estàtic, sinó que també es col·loca en una perspectiva dinàmica: un centre en una àrea metropolitana ha d'emetre una *ombra d'aglomeració* (efectes de l'ombra sobre el creixement) sobre els seus voltants; això vol dir que el nombre d'empreses i la quantitat de desenvolupament urbà (creixement) en àrees properes a un centre seran limitats a causa d'efectes de competència ferotge.

En segon terme, aquesta tesi ha proposat un marc conceptual per explorar la relació entre policentrisme (a l'escala intraurbana) i l'eficiència territorial metropolitana, amb l'objectiu de permetre una examinació àmplia dels efectes del policentrisme. Basant-se en la relació entre les teories de l'aglomeració i policentrisme en la literatura, aquesta tesi sosté que la consideració de tres dimensions diferents d'una estructura espacial policèntrica que prenen part en el desenvolupament de les economies d'aglomeració en una àrea metropolitana—específicament, (1) la mida dels centres, (2) la proximitat (geogràfica) als centres, i (3) la mida agregada dels centres mitjançant la seva integració—permet extreure conclusions més àmplies sobre els efectes del policentrisme. La traducció d'aquestes tres dimensions d'una estructura metropolitana en un marc empíric més complet i sistemàtic ha requerit l'examinació dels efectes (1) d'estar localitzat en els centres o orientat cap als centres, (2) d'estar localitzat a prop dels centres, i (3) dels patrons d'interacció entre els centres.

Conclusions

A continuació es presenten les principals conclusions respecte a les tres preguntes de recerca generals.

Com ha evolucionat la conceptualització del desenvolupament policèntric en els plans territorials amb el temps, i què es pot aprendre d'aquesta evolució?

Concebre una visió territorial basada en el desenvolupament policèntric per als plans territorials ha esdevingut un tret distintiu de la praxi de la planificació territorial a Catalunya. La primera visió de desenvolupament policèntric apareix durant la dècada de 1930 com a resposta al debat en l'oposició urbà-rural entre Barcelona (ciutat) i Catalunya (país), resultat d'un increment de les demandes per abordar els reptes plantejats per la industrialització de les ciutats. Des de llavors, la visió territorial d'un desenvolupament policèntric en els plans territorials evoluciona, mostrant dos patrons de transició en la seva conceptualització en plans territorials successius. La primera transició exposa que malgrat el policentrisme va ésser primerament conceptualitzat com una estratègia de descentralització encaminada a restringir el creixement de Barcelona, més tard és conceptualitzat com un model territorial que pot organitzar i canalitzar el desenvolupament urbà a partir de treure profit de les dinàmiques urbanes. La segona transició es manifesta a través d'afegir la percepció de xarxa de ciutats a la visió de desenvolupament policèntric. Aquesta noció de xarxa policèntrica de ciutats contribueix definitivament a resoldre l'antagonisme entre Barcelona i Catalunya, doncs integra la capital de Barcelona en un model territorial policèntric per a tot el territori de Catalunya.

La praxi del desenvolupament policèntric en diferents plans territorials a Catalunya també exposa algunes deficiències derivades dels enfocaments prescriptius o normatius utilitzats pels plans territorials per definir el desenvolupament policèntric, en els quals no es considera l'evidència empírica del territori existent. No obstant, la consideració simultània de totes les conceptualitzacions de desenvolupament policèntric encunyades pels plans territorials—i per tant, quan el paper exercit per factors diferents de l'evidència empírica, com ara els interessos i els costums de regulació de les institucions, pot ésser identificat més clarament—posa de manifest que algunes de les deficiències en la definició d'una estratègia de desenvolupament policèntric poden explicar-se pel fet que, en certa mesura, els plans territorials estan polititzats. Això planteja el repte de construir una visió del desenvolupament policèntric més estretament relacionada amb el debat acadèmic actual sobre el policentrisme i, per tant, hi ha la necessitat d'una planificació territorial més informada per l'evidència empírica, que té com a finalitat la utilització d'un coneixement més acurat del policentrisme, sobretot respecte a la conceptualització d'aquest (identificació i mesura) i els seus efectes en l'eficiència econòmica, social, i ambiental de les àrees metropolitanes. Els actors públics i privats que influencien les polítiques territorials, per exemple, a través de la seva ideologia o interessos, tindrien un rol

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rellevant en la implementació d'aquesta visió de desenvolupament policèntric, basat en considerar (o no) les directrius/recomanacions per a l'elaboració de polítiques derivades de l'evidència empírica i destinades a millorar l'eficàcia i viabilitat dels plans territorials.

Com ha estat conceptualitzat el policentrisme en l'àmbit de la recerca, i com pot informar la praxi de la planificació territorial?

Una integració més gran entre estudis sobre la conceptualització del policentrisme potencialment informa els plans territorials sobre l'eficàcia i viabilitat de les estratègies de desenvolupament policèntric. Aquesta integració ha fet evident el mètode (empíric o no empíric) d'identificació de centres que defineix més acuradament el model policèntric en la regió metropolitana de Barcelona; pas essencial per corroborar empíricament el vincle entre policentrisme i eficiència territorial en una àrea metropolitana, doncs les diferències en la identificació de centres poden derivar-se en conclusions diferents sobre la comprensió dels costos i beneficis d'una estructura metropolitana policèntrica. El principal avantatge del nou mètode d'identificació de centres proposat i avaluat en aquesta tesi és que té en compte les diferents vies per les quals els centres poden sorgir, específicament, la trajectòria de descentralització i la de incorporació-fusió. Aquest mètode ha estat el més vàlid per identificar com a centres aquelles ciutats que tenen el nivell més alt d'economies d'aglomeració i que projecten les ombres d'aglomeració més severes sobre els seus entorns.

D'altra banda, la incorporació de la dimensió morfològica i funcional del policentrisme—tal com la literatura sobre el policentrisme a l'escala interurbana ha adoptat—en la mesura del grau del policentrisme a l'escala intraurbana ha contribuït a la creació d'arguments més sòlids a favor o en contra pel que fa al suport a una estratègia de desenvolupament policèntric en una àrea metropolitana. A més, també ha aportat als urbanistes un coneixement útil, no només pel que fa a com abordar els problemes relacionats amb la visió, les implicacions de governança, i les expectatives del desenvolupament policèntric sinó també respecte a com monitoritzar la implementació d'una estratègia de desenvolupament policèntric.

En quina mesura el policentrisme fomenta una major eficiència territorial en una àrea metropolitana, i com els seus efectes es poden realitzar en la praxi de la planificació territorial?

Una estructura metropolitana policèntrica exerceix una influència considerable—tant activa com passiva—per augmentar l'eficiència territorial en una àrea metropolitana a través del comportament de la mobilitat de les persones. Els efectes del policentrisme—això és, (1) d'estar localitzat en els centres o orientat cap als centres, (2) d'estar localitzat a prop dels centres, i (3) dels patrons d'interacció entre els centres—generalment són més grans que els efectes de les característiques específiques de les persones—és a dir, característiques sociodemogràfiques i actituds relacionades amb la mobilitat—i dels atributs del medi construït per tal de promoure que les persones utilitzin mitjans de transport més sostenibles de manera més freqüent (transport públic i mitjans de transport no motoritzats) i reduir les externalitats de la mobilitat—és a dir, distància de viatge, temps de viatge, i emissions de CO_2 relacionades amb el transport. Més específicament, la dimensió més important d'una estructura metropolitana policèntrica per fomentar un patró de mobilitat més sostenible és, generalment, el tipus de interacció, seguit pel tipus de ciutat, que a la vegada és més important que la distància als centres.

Partint d'aquests efectes, el desenvolupament policèntric fomenta una eficiència territorial més gran en la regió metropolitana de Barcelona perquè ha influït en el comportament de la mobilitat de les persones mitjançant tres dimensions diferents. En primer lloc, les persones que viuen o realitzen les seves activitats diàries en els centres utilitzen el transport públic o mitjans no motoritzats més freqüentment, i els seus desplaçaments són més curts, de menys durada, i causen menys emissions de CO_2 relacionades amb el transport en comparació amb les persones que no viuen o no realitzen les seves activitats en aquests centres. En segon lloc, les persones que viuen a prop dels centres exhibeixen un patró de mobilitat més sostenible que les persones que viuen més lluny dels centres. En tercer lloc, les persones que es desplacen entre centres són més propenses a utilitzar transport públic, i experimentar distàncies o temps de desplaçament més curts així com també a produir una reducció més gran de les emissions de CO_2 derivades del transport en comparació amb les persones que es desplacen entre les àrees perifèriques. En resum, els beneficis de l'aglomeració en una regió metropolitana policèntrica expliquen el perquè d'aquests tres resultats de recerca esmentats. Per tant, la traducció dels beneficis del policentrisme en polítiques de planificació territorial requereix la consideració simultània (1) de la mida dels centres, (2) de la mida dels centres i la proximitat (geogràfica) als centres i, (3) de la mida dels centres i la integració entre centres.

Directrius d'evidència informada per a les polítiques de planificació territorial

Els efectes estimats del policentrisme en el comportament de la mobilitat de les persones donen lloc a l'elaboració d'un conjunt de directrius per a la política de planificació territorial pel que fa al desenvolupament urbà i d'infraestructures. Aquestes polítiques de planificació territorial informen els autors dels plans territorials sobre com els beneficis del policentrisme es poden realitzar en la praxi de la planificació territorial, i per tant, els aporta un coneixement més acurat del desenvolupament policèntric per tal de poder assolir amb més eficàcia els objectius econòmics, socials i ambientals dels plans territorials.

En essència, la traducció dels beneficis del policentrisme en directrius d'evidència informada per a les polítiques de planificació territorial ha requerit la consideració de diverses dimensions d'una estructura espacial policèntrica que prenen part en el desenvolupament dels beneficis d'aglomeració en una àrea metropolitana: (1) la mida dels centres, (2) la proximitat (geogràfica) als centres, i (3) la mida agregada dels centres mitjançant la seva integració. S'han elaborat set recomanacions de política de planificació territorial per millorar l'eficàcia dels objectius de planificació territorial del Pla Territorial Metropolità de Barcelona del 2010, respecte als costos de mobilitat de les persones i l'impacte ambiental de la mobilitat.

Mida agregada dels centres mitjançant la seva integració

1. Suport a noves i més eficients xarxes de transport públic entre els centres per fer possible que aquests centres treguin més profit de la seva mida urbana agregada, fet que resulta en un desenvolupament més gran d'economies d'aglomeració.
2. Augmentar la complementarietat entre els centres a l'escala metropolitana en termes de sectors econòmics, ocupacions, i funcions urbanes, a través de promoure estratègies de ciutat compacta ('compact-city') i desenvolupament orientat al transport públic ('transit-oriented development').
3. Suport a noves i més eficients xarxes de transport públic entre els centres i les àrees del seu entorn per tal d'estimular interaccions cap als centres i augmentar l'accés dels residents propers als centres als beneficis de l'aglomeració dels centres que estan integrats amb el seu centre més proper.
4. Suport a noves i més eficients xarxes de carretera entre els centres secundaris per tal de reduir la congestió al llarg dels eixos de transport radials orientats cap a la ciutat central de Barcelona.

Mida dels centres

5 Promoure estratègies de ciutat compacta i desenvolupament orientat al transport públic en els centres existents (ciutat central i centres secundaris) per estimular que més residents d'aquests centres puguin accedir als seus beneficis d'aglomeració.

Proximitat als centres

6 Promoure estratègies de ciutat compacta i desenvolupament orientat al transport públic en ciutats properes als centres per fer possible que més residents d'aquestes àrees en els entorns dels centres puguin treure profit de la seva proximitat als beneficis de l'aglomeració d'un o més centres.

7 Limitar el creixement en àrees localitzades a gran distància dels centres, tant per reduir (el màxim possible) els alts costos de la mobilitat (distància i temps de desplaçament) que afecten els residents en aquestes àrees perifèriques, com per disminuir les emissions de CO_2 relacionades amb el transport que causen aquests residents.

Agenda per a la recerca i la política territorial

Tot i aportar noves perspectives i marcs teòrics i empírics per analitzar les múltiples relacions entre policentrisme, eficiència territorial i planificació territorial en les regions metropolitanes, és necessari dur a terme més recerca per abordar una sèrie de reptes i llacunes de recerca que aquesta tesi no ha pogut cobrir en la seva totalitat. Aquests reptes i llacunes de recerca fan referència tant al cas de la regió metropolitana de Barcelona com a avanços més generals que són necessaris en les relacions recíproques entre policentrisme, eficiència territorial i planificació territorial.

L'interès de l'anàlisi empírica d'aquesta tesi en el comportament de la mobilitat de les persones s'ha d'ampliar per tal d'assolir conclusions més àmplies sobre el efectes del policentrisme en l'eficiència territorial de la regió metropolitana de Barcelona. A més, l'anàlisi empírica d'aquesta tesi s'ha d'estendre per elaborar directrius més exhaustives d'evidència informada per a les polítiques de planificació territorial que abordin tots els objectius de planificació territorial del Pla Territorial Metropolità de Barcelona del 2010. Es poden identificar dues perspectives d'investigació futura per abordar aquestes demandes. En primer lloc, l'objecte d'anàlisi podria estendre's des de les persones cap a les empreses i el seu comportament espacial. En segon lloc, es podria considerar una gamma més àmplia d'externalitats. En el futur, seria d'interès especial dur a terme recerca sobre la relació entre policentrisme i altres indicadors d'eficiència territorial, com ara la productivitat laboral, la desocupació, els preus de l'habitatge i del sòl, els ingressos per càpita, les emissions de CO_2 relacionades amb la llar, i el consum de sòl.

El tipus d'exploració realitzada en aquesta tesi, cas d'estudi únic, demana més investigació per determinar si les seves conclusions poden ser corroborades en altres àrees metropolitanes. Es podrien tenir en compte molts punts de vista sobre recerca en el futur, però probablement els més importants són els dos que s'expliquen tot seguit. El primer implicaria dur a terme una recerca basada en múltiples casos d'estudi amb l'objectiu d'examinar els efectes del policentrisme en l'eficiència territorial utilitzant els indicadors d'eficiència territorial descrits més amunt i considerant—i si és possible, estendre—el marc conceptual proposat en aquesta tesi i mencionat anteriorment. El segon implicaria fer també una recerca basada en múltiples casos d'estudi, però aquesta vegada amb l'objectiu d'avaluar el mètode d'identificació de centres proposat en aquesta tesi en relació amb altres mètodes d'identificació.

PART 1 Introduction and research framework of the triple Ps: polycentricity, performance and planning

1 Introduction

§ 1.1 Opening the debate about polycentricity

More than half of the world's population lives in urban settlements, a proportion that is expected to increase to more than 65 percent by 2050 (UN, 2014). The larger agglomerations are a complex spatial configuration of places and flows that are polycentric by nature, or at least they demonstrate a certain development of a multi-center structure. Recently, the focus on agglomerations' polycentric structure has attracted a great deal of attention from both researchers and policymakers, who must manage the economic, social, and environmental challenges that the population of these metropolitan agglomerations will experience in the coming decades.

In research, a considerable portion of the study of polycentric agglomerations has focused on the conceptualization of polycentricity on distinct territorial scales and the empirical analysis of its economic, social, and environmental (dis)advantages. Most of this academic effort has been published in special issues of journals such as *European Planning Studies* (1998, 6.4; 2004 12.4; 2015, 23.6), *Urban Studies* (2001, 38.4), *Built Environment* (2005, 31.2; 2006, 32.2), and *Regional Studies* (2008, 42.8; 2014, 48.12) or books such as Lee (2006a), Limtanakool (2006), Meijers (2007a), Lambregts (2009), Burger (2011), and Delage (2012). In the policy realm, polycentric development appears to be the primary hallmark of spatial plans for metropolitan areas worldwide. Indeed, more than 75 percent of recent spatial plans developed for large metropolitan areas in OECD countries consider polycentric development as the best strategy for managing urban development. Some of the key policy objectives that polycentric development is expected to fulfill include offering an economical, efficient transportation system and a sustainable environment, along with extending access to education, jobs, amenities, and decent housing to a large number of people.

This doctoral dissertation attempts to broaden the appeal of metropolitan agglomerations and polycentricity in both research and policy by conducting research that links knowledge of polycentric constellations and their economic, social, and environmental effects to planning practice and policy in metropolitan areas. More specifically, this thesis focuses on how the multiple relationships among polycentricity, performance, and planning manifest themselves in the Barcelona metropolitan region. With approximately 5 million people, the Barcelona metropolitan region is the primary urban agglomeration of Catalonia, an autonomous region of 7.5 million inhabitants that is located in Spain.

The remainder of the introduction is organized as follows. Section 1.2 outlines the historical roots of the polycentricity debate in research, whereas section 1.3 focuses on how polycentricity is understood in recent spatial planning policies. Section 1.4 sets out the general aims and questions of this dissertation to address the major problems to be solved in relation to polycentric metropolitan agglomerations. Finally, section 1.5 presents the single case study of this thesis and section 1.6 presents its organization.

§ 1.2 In research

The current appeal for metropolitan agglomerations and polycentricity made by planners, geographers, economists, and policymakers alike is far from new. It is rooted in various ideas about the conceptual extension of urban areas and multi-center forms that were introduced in geographical studies more than 50 years ago. It was Jean Gottmann (1957, 1961), a French geographer, who first envisioned the rise of an enlarged, borderless, and continuous urban reality of core and suburban zones along the northeastern coast of United States caused by the growing interdependencies among urban areas resulting from technological change (e.g., telephones and automobiles). Gottmann coined this new urban scale the 'megalopolis', stating that it reflected the shift from a metropolitan area with a single main center to a metropolitan area with multiple centers that function as a single integrated entity. Gottmann's ideas about the transforming spatial organization of urban regions were widely acclaimed in the early 1960s and over time, other related conceptual approaches to defining the physical and functional characteristics of such enlarged scales of urbanity were developed, including the 'dispersed city' (Burton, 1963), the 'regional city' (Stein, 1964), 'urban fields' (Friedmann and Miller, 1965), and the 'functional economic area' (Berry et al., 1968).

Planners also embraced these ideas on the transformation of urban areas. Peter Hall (1966) even observed that the medium-sized, close-by and specialized centers in the Randstad-Holland and Rhine-Ruhr regions would qualify as 'World Cities,' which he defined as a 'polycentric type of metropolis' that contrasted markedly with monocentric regions such as London and New York. In the 1960s, the relatively radical change in perception of urban regions' spatial organization from monocentric to networked polycentric forms triggered a variety of novel spatial plans, which broke with the then-dominant spatial strategies that adopted ideas of concentric urban zones, green belts, satellite cities and central-place hierarchies based on the work of early 20th-century planners (Mumford, 1938) and geographers (Christaller, 1933; Harris and Ullman, 1945). Novel plans included the 1963 *Piano Intercomunale Milanese*, the 1965 *Schéma Directeur d'Aménagement et d'Urbanisme de la Région de Paris*, and the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona*. These plans particularly emphasized the need for a polycentric model to address urbanization pressure on the main center of the agglomeration. The establishment of a tangential transport infrastructure model connecting existing centers with areas of new growth and the prevalence of non-hierarchical relationships among centers were seen as the primary spatial concepts to develop this planning vision of a networked polycentric metropolitan area.

Although polycentric urban forms had already been identified and conceptualized, the whole concept did not receive much attention in the 1970s and early 1980s and consequently, little progress was made in the study of such regions. Perhaps this was caused by the emerging neoliberal perspective that emphasized the national state organization in which the integration of countries into a more global economic market and issues such as unemployment and deindustrialization drew most political attention, resulting in regions and their role as actors of economic development being largely overlooked (Burger, 2011; Lambregts, 2009). Therefore, most academic discourses were concerned about the global scale in an effort to address the challenges of the ongoing economic restructuring of that time (Coffey et al., 1998). That said, the late 1980s and early 1990s saw a renewed academic interest in metropolitan agglomerations. Various studies in several disciplines observed an increasing disconnection between urban reality and existing theoretical approaches to urban systems, primarily as a consequence of the rapid suburbanization of jobs, population and urban functions, advances in transport, information and communication technologies, and changes in household structures and lifestyles. According to economists, geographers, and planners, this disconnection demanded further research on a distinctly territorial scale (e.g., metropolitan or regional) to address these changing realities.

In general, three main strands of literature can be distinguished. In New Urban Economics, formal theoretical models were developed to explain the new urban reality. Initially, those models included suburbanization growth patterns in the 1970s. Later, models were developed to predict the rise of a polycentric spatial configuration in metropolitan areas because of the shifting relationships between and within firms and the growing significance of agglomeration economies in the spatial distribution of employment, population, and urban functions (Fujita, 1988; Fujita and Owaga, 1982). New concepts such as 'edge cities' (Garreau, 1991) 'suburban downtowns' (Stanback, 1991), and 'subcenters' (Gordon and Richardson, 1996) were introduced by scholars to explain the growing spatial concentration of office, retail, and often residential functions in multiple suburban zones, mostly linked to major transportation networks, forming a polycentric type of metropolitan agglomeration (Erickson, 1983; Gordon et al., 1986; Greene, 1980). Additionally, economists drew special attention to the reformulation of the paradigm of hierarchical urban systems (see Christaller, 1933) to explain the trajectory toward a polycentric form. In particular, the New Economic Geography that appeared in the 1990s (Fujita and Mori, 1997; Fujita et al., 1999a, 1999b) developed theoretical models to explain the monocentric-to-polycentric transition through changes in the urban hierarchy and spatial location of cities caused by the interplay between agglomeration and agglomeration diseconomies. More specifically, these models formalized the formation of polycentric spatial configurations caused by the increasing interaction among centers and their covered marked areas, which in turn led to the functional integration of either similar or distinct rank centers in a metropolitan region, either through incorporation or the coalescence of formerly distinct centers.

The second strand of literature was primarily carried out by geographers, who reformulated the paradigm of hierarchical urban systems and therefore stressed the Central Place Theory's (Christaller, 1933) limitations in explaining the reality of urban systems since the late 1980s. In particular, geographers developed the Network System paradigm (e.g., Batten, 1995; Camagni and Salone, 1993) that essentially contributed to an understanding of the spatial organization of urban regions as a polycentric network of centers. This meant that urban systems were increasingly depicted by the presence of both two-way linkages and complementary and cooperative relationships among centers of similar and different size—unlike Central Place Theory, which essentially describes urban systems in terms of their one-way flows towards the highest-ranking centers and the absence of complementary relationships.

The third strand of academic research was related to the emergence of several planning concepts since the 1990s to explore and identify polycentricity's potential on larger territorial scales than that defined by a single metropolitan area (see Davoudi, 2003). Examples of these concepts initially included the 'network city' (Batten, 1995) and the 'polynucleated metropolitan region' (Dieleman and Faludi, 1998), until the term 'polycentric urban region' took root through—in particular—the study by Kloosterman and Musterd (2001). The latter term can be defined as a dense network of various historically distinct—but adjacent—city-regions that engaged in important functional interactions among their leading centers (Kloosterman and Musterd, 2001; Parr, 2004). In subsequent years, concepts such as the 'mega-city region' (Hall and Pain, 2006) and the 'megapolitan region' (Lang and Knox, 2009) also explored the regional development of adjacent urban regions that were linked by complex flows of people, goods, and information.

The main point of interest is that these polycentric constellations on different territorial scales have often been considered to perform better than their monocentric counterparts. Whereas economists have frequently paid attention to the relationship between polycentricity and performance on the scale of a single metropolitan area, geographers and planners have often examined that relationship on a territorial scale defined by several separated city-regions. For example, economists have suggested that the appearance of multiple centers in a metropolitan area results in important competitive advantages because agglomeration diseconomies that emerge in a monocentric metropolitan area with a single center—e.g., pollution, congestion, high land prices, and commuting costs—are mitigated, whereas firms and households could continue to benefit from the agglomeration benefits—e.g., greater productivity, more innovative opportunities for firms and more opportunities for both firms and people to learn and acquire skills (Fujita and Owaga, 1982; Fujita et al., 1997; Sasaki and Mun, 1996; White, 1999)—that arise out of the presence of several centers. Planners and geographers have similarly highlighted that 'polycentric urban regions' can be more competitive than their monocentric counterparts because they can provide a better balance between the positive aspects of agglomeration (e.g., access to wide labor markets) and the negative aspects of agglomeration (e.g., crime, pollution and congestion) (Faludi, 2004a; Meijers, 2007a; Parr, 2004).

§ 1.3 In policy

Policy experts' current interest in polycentricity is rooted in the early 1990s, when after two decades of focusing on local urban development projects and land-use regulations, planning practice refocused its attention on producing strategic frameworks and visions for territorial development in cities and metropolitan regions, strongly emphasizing their relationship with *sustainable development* (Albrechts et al., 2003). Polycentric development therefore re-entered planning practice as a bridging concept between *sustainable development* (broadly interpreted as fulfilling economic, social, and environmental objectives) and territorial development. The most important European example of this phenomenon is the European Spatial Development Perspective, which was adopted by the EU 15 Member States and the European Commission in 1999. This planning policy document perceived the concept of polycentric development as a normative tool to promote economic competitiveness, territorial cohesion, and sustainable development within and across European regions and countries. For instance, the European Spatial Development Perspective argued that polycentric development triggers a more balanced spatial distribution across urban nodes and allows various nodes not only to benefit from economies of scale but also to specialize in particular economic activities and urban functions (EC, 1999).

Today, polycentric development also appears as the main hallmark of spatial plans for metropolitan areas worldwide, as shown in Table 1.1. Indeed, more than 75 percent of recent spatial plans developed either in large metropolitan areas (as identified by the OECD (2012)) or in other 'global cities' (such as Beijing, Rio de Janeiro, Hong Kong, Singapore, and Sydney) perceive polycentric development as the best territorial development strategy for achieving *sustainable development* as defined in terms of economic, social, and environmental goals. Those key planning objectives that polycentric development is expected to attain include, for example, an economical, efficient transportation system and a sustainable environment, along with extending access to education, jobs, amenities, and decent housing to a large number of people.

The understanding of polycentric development in current planning policies, however, appears largely disconnected from the ongoing polycentricity debate in the research discussed above. This lack of connection between the understanding of polycentricity in research (evidence) and in policy (spatial plans), as revealed in Table 1.1, becomes apparent in the issues of how polycentric development can be conceptualized in spatial plans and how the assumed benefits of polycentricity can be realized in planning practice. Both of these two points provide reasons for the call for spatial plans to consider evidence-informed knowledge to improve the effectiveness and feasibility of their polycentric development. Of course, this call does not argue that evidence should be the only contender for influencing policy because spatial plans are politicized and other factors such as ideology and interests also play an important role (see, e.g., Davoudi, 2006; Faludi and Waterhout, 2006; Weiss, 2001). Nevertheless, it argues that the use of an improved understanding of polycentricity in planning policies that results from closer attention to the ongoing polycentricity debate in the research could contribute to enhance the feasibility and effectiveness of the economic, social, and environmental objectives of spatial plans.

In terms of how polycentric development can be interpreted in spatial planning policies, the first issue refers to existing approaches to identify and define the polycentric model of plans because in general, hardly any attention has been paid to the use of an empirical method to define the centers that shape the polycentric structure of a metropolitan area (see columns 4-6 in Table 1.1). Whereas most spatial plans have proposed a polycentric territorial model by identifying centers on a map in accordance with the planning concept proposed, few spatial plans have defined their territorial model either by empirically identifying centers that use a method derived from, e.g., the urban economics literature (2010 Chicago and 2012 Montreal), or by considering the opinion of stakeholders involved in their elaboration (Houston-Galveston, in progress). Perhaps this is the reason that several planning concepts have appeared to define what a polycentric territorial model could be. For example, the polycentric territorial model has been defined as a 'circular megalopolis structure' (2004 Tokyo), a 'multi-core or polycentric structure with development axis' (e.g., 2013 Seoul or 2014 Singapore), a 'polycentric structure in two-axes-two-belts' (2004 Beijing), a 'polycentric network of cities or town centers' (e.g., 2010 Barcelona or 2011 London), a 'polycentric city with specialized centers' (e.g., 2014 Melbourne), or even as a 'system of central places' (e.g., 2009 Berlin-Brandenburg). Furthermore, a second issue refers to the paucity of attention paid by spatial plans to measuring an entire metropolitan area's degree of polycentricity (see column 7 in Table 1.1). It may be that examining the extent to which a polycentric development strategy is unrelated to the evidence of whether a metropolitan area is already polycentric could shed light on the feasibility of such a strategy. For instance, the establishment of an efficient public transportation system between a metropolitan area's centers to enhance environmental sustainability is more viable if those centers have a strong level of both spatial integration and complementarity.

Referring to how the assumed benefits of polycentricity can be realized in planning practice, one main issue refers to the lack of *ex ante* empirical analysis and *ex post* impact evaluation to examine the economic, social, and environmental effects and consequences that arise out of the polycentric territorial model proposed by spatial plans (see column 8 in Table 1.1). Although planning practice has concentrated its efforts on providing long-term forecasts (up to a horizon year) of the population, the labor market, housing and occasionally land use and the environment, it has not attempted to empirically substantiate the relationship between polycentricity and performance in metropolitan areas. Only few spatial plans—e.g., the 2010 Toronto Official Plan, the 2013 Plan Bay Area (San Francisco), and the 2014 Plan for Growing Sydney—have developed a set of performance indicators to *ex post* evaluate the extent to which their planning objectives are fulfilled.

METROPOLITAN AREA	NAME OF PLAN / YEAR OF APPROVAL	FORECAST SCENARIOS (PROJECTIONS)	PRIMARY SPATIAL DEVELOPMENT STRATEGY
Tokyo	Master Plan for City Planning / 2004 & Planning Vision for Tokyo / 2009	Population, labor market, and housing (2011-2020)	Circular megalopolis structure
Seoul	2030 Seoul Plan (Seoul's Master Plan) / 2013	Population, labor market, and housing (2013-2030)	Multi-core structure with development axis
Shanghai	Shanghai Master Plan / 2001	Population, labor market, and housing (1999-2020)	Multi-center and multi-axis spatial structure
Mexico city	Plan of the Metropolitan Area of Mexico city—POZMVM / 2012	No	Polycentric network of cities
Osaka-Kansai	Future Vision of Osaka / scheduled for completion in 2025	No	Multi-core structure with development axis
Los Angeles	Los Angeles County 2035 General Plan / draft in 2014	Population, labor market, and housing (2008-2035)	Multi-core structure and 'Transit-Oriented Development'
New York	PlaNYC / 2007	Population, housing, jobs, and the environment (2007-2030)	'Transit-Oriented Development'
Beijing	Beijing Urban Master Plan / 2004	Population, jobs, and land allocation (2004-2020)	Polycentric structure in 'two-axes-two belts'
Rio de Janeiro	Metropolitan urban and housing development policy loan—DPL / 2011	No	Integration between transport and development
London	The London Plan: A Spatial Development Strategy for Greater London / 2011	Population, housing, jobs, and the environment (2011-2031)	Polycentric network of 'town' centers
Paris	Schéma Directeur Région Île-de-France—SDRIF / 2013	Population, housing, jobs, and the environment (2013-2030)	Intense, compact, and polycentric development
Sao Paulo	SP2040 A Cidade que queremos / 2012	No	Compact and polycentric development
Chicago	Go to 2040 Comprehensive Regional Plan / 2010	Population, jobs, housing and climate change (2000-2040)	Polycentric network of urban areas
San Francisco	Plan Bay Area / 2013	Population, housing, jobs, and the environment (2013-2040)	Polycentric structure with 'Transit-Oriented Development'
Hong Kong	Hong Kong 2030: Planning Vision and Strategy / 2007	Population, housing, jobs, and the environment (2003-2030)	Multi-center structure with development axis
Toronto	Toronto Official Plan / 2010	Population, jobs, and land use (2011-2041)	Polycentric structure: mixed use communities
Santiago de Chile	Regional Development Strategy of Santiago Metropolitan Region / 2012	No	Polycentric structure with development axis
Houston	Houston-Galveston Regional Plan / in progress since 2014	Not yet complete	Polycentric structure with 'Transit-Oriented Development'
Miami	Comprehensive Development Plan for Miami-Dade County / 2013	Population and employment (2010-2030)	Polycentric network of urban areas
Singapore	Master Plan 2014 / 2011 & Concept Plan 2011 / 2014	Population, housing, land use, the environment, and jobs (2010-2030)	Polycentric structure with development axis
Washington	Region Forward / 2010	Population, housing, land use, the environment, and jobs (2010-2040)	Polycentric network of urban areas
Johannesburg	Integrated Development Plan: Joburg 2040 Strategy / 2012	No	Polycentric structure with development axis
Atlanta	Atlanta Region Plan 2040 / 2010	Population, housing, land use, the environment, and jobs (2010-2040)	Polycentric structure with development axis
Berlin	State Development Plan Berlin-Brandenburg—LEP B-B / 2009	Population, jobs, and housing (2009-2030)	Polycentric structure ('System of Central Places')
Sydney	A Plan for Growing Sydney / 2014	Population, housing, land use, the environment, and jobs (2016-2031)	Polycentric structure and 'Transit-Oriented Development'
Melbourne	Plan Melbourne: Metropolitan Planning Strategy / 2014	Population, jobs, housing, and land use (2014-2050)	Polycentric city with specialized centers
Montreal	Metropolitan Land Use and Development Plan—PMAD / 2012	Population, jobs, and housing (2011-2031)	Polycentric structure with specialized centers
Monterrey	Metropolitan Vision: Monterrey 2030 / 2007	No	Polycentric network of cities
Milan	Territorial Plan of Province Coordination—PTCP. Province of Milan / 2013	Population, jobs, and housing (2013-2020)	Polycentric network of cities
Philadelphia	Connection 2040. Plan for Greater Philadelphia / 2009	Population, jobs, and funding allocation (2010-2040)	Polycentric network of urban areas
Rome	Provincial General Territorial Plan—PTPG. Province of Rome / 2010	Population, jobs, and housing (2001-2015)	Polycentric network of cities
Phoenix	Phoenix General Plan (planPHX) / 2015	Population, jobs, and housing (2015-2030)	Polycentric structure and 'Transit-Oriented Development'
Barcelona	Barcelona Metropolitan Territorial Plan—BMTP / 2010	Population, labor market, and housing (2001-2026)	Polycentric network of cities

	POLYCENTRIC DEVELOPMENT / NUMBER OF CENTERS	METHOD OF IDENTIFYING CENTERS	MEASUREMENT OF POLYCENTRICITY	POLYCENTRICITY AND PERFORMANCE
	Yes / Central core and 4 centers' axis (e.g., Saitama)	Not empirical	No	No
	Yes / 3 main centers, 7 regional, and 12 local centers	Not empirical	No	No
	Yes / 1-9-6-6 model (core, new cities, small cities, and villages)	Not empirical	No	No
	Yes / 12 centers (5 primary and 7 complementary)	Not empirical	No	No
	Yes / Central core and 7 other centers (e.g., Saito area)	Not empirical	No	No
	Yes / Transit, neighborhood, and rural town centers	Not empirical	No	No
	No / 'Transit-Oriented Development' areas (e.g., Downtown Jamaica)	No identification of centers	No	No
	Yes / Central city and 14 other centers (e.g., BDA)	Not empirical	No	It only defines performance indicators
	No	No identification of centers	No	No
	Yes / Inner London and 12 other centers (e.g., Kingston)	Not empirical	No	No
	Yes / Inner Paris and 21 regional centers (e.g., Évry)	Not empirical	No	No
	Yes / Economic, technological, and institutional centers	Not empirical	No	It only defines performance indicators
	Yes / Central city and 31 other centers (e.g., Schaumburg)	McMillen (2003b): job thresholds	No	It only defines performance indicators
	Yes / 10 types of centers (e.g., city, regional, suburban)	Not empirical	No	It only defines performance indicators
	Yes / Inner city and a set of centers (e.g., Fanling North)	Not empirical	No	It only defines performance indicators
	Yes / Central city and 5 other centers (e.g., Etobicoke)	Not empirical	No	It only defines performance indicators
	Yes / Santiago and 9 other centers (e.g., Talagante)	Not empirical	No	No
	Yes / Central city and 12 other centers (e.g., Uptown)	Not empirical	No	It only defines performance indicators
	Yes / Inner core and 13 other regional centers (e.g., FIU)	Not empirical	No	No
	Yes / Central area and 19 other centers (e.g., Tampines RC)	Not empirical	No	No
	Yes / Central area and 140 other centers (e.g., St. Elizabeth's)	Housing and jobs thresholds	No	It only defines performance indicators
	Yes / Central city and 22 other centers (e.g., Midrand)	Not empirical	No	No
	Yes / Regional core and 15 other centers (e.g., Cumberland)	Not empirical	No	It only defines performance indicators
	Yes / Berlin and 4 other regional centers (e.g., Potsdam)	Not empirical	No	No
	Yes / 2 central cities (Sydney, Parramatta) and 3 other centers	Not empirical	No	It only defines performance indicators
	Yes / Central city and 6 other centers (e.g., Monash)	Not empirical	No	It only defines performance indicators
	Yes / Central city and 5 primary poles (e.g., Longueuil)	Shearmur (2006): job thresholds	No	No
	Yes / Central city and 10 other centers (e.g., Santa Caterina)	Not empirical	No	No
	Yes / Central city and 10 other centers (e.g., Abbiategrasso)	Not empirical	No	No
	Yes / Central city and 6 other centers (e.g., Trenton)	Not empirical	No	It only defines performance indicators
	Yes / Central city and 20 other centers (e.g., Pomezia)	Not empirical	No	No
	Yes / Central city and 21 other centers (e.g., Deer Valley)	Not empirical	No	No
	Yes / Barcelona and 7 other centers (e.g., Sabadell, Terrassa)	Not empirical	No	No

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METROPOLITAN AREA	NAME OF PLAN / YEAR OF APPROVAL	FORECAST SCENARIOS (PROJECTIONS)	PRIMARY SPATIAL DEVELOPMENT STRATEGY
Boston	Metro Future. Making a Greater Boston region / 2008	Population, labor market, and housing (2008-2030)	Polycentric network of cities
Athens	Regulatory (Master) Plan for Athens-Attiki—2021 / 2011 (finished)	No	'Hierarchical' urban network with 3 types of centers
Curitiba	Director Plan of Curitiba / 2014	No	Polycentric structure with 'Transit-Oriented Development'
München	Regional Plan of München / 2001	No	Polycentric structure ('System of Central Places')
Lisboa	Regional Action Plan of Lisboa / 2014	No	Network of the cities that comprise the region
Vienna	Step 2025. Urban Development Plan Vienna / 2014	Population, along with housing and mobility projects (2013-2025)	Strengthening of the polycentric urban structure
Frankfurt-RheinMain	The Regional Preparatory Land Use Plan of Frankfurt-RheinMain /2011	No	Network of mid-sized centers with development axis
Bruxelles	Plan Régional de Développement Durable—PRDD / 2013	No	Multi-center and mosaic structure of the territory
Amsterdam	Structural Vision: Amsterdam 2040 / 2011	Population and housing (2010-2040)	Polycentric structure with a dense core city
Rotterdam Den Haag	Strategic Agenda Rotterdam-Den Haag metropolitan region / 2013	No	Polycentric structure with 'Transit-Oriented Development'
Portland	The Portland Plan / 2012	Housing (2015-2035)	Polycentric network of urban areas
Copenhagen	Fingerplan (Copenhagen) / 2013	Population and housing (2011-2030)	'Transit-Oriented Development' based on 5 development axis (fingers)
Stockholm	Regional Development Plan for Stockholm Region—RUFS / 2010	Housing and population (2010-2030)	Polycentric network of cities
Lyon	SCOT 2030. Projet d'Aménagement et de Développement Durable / 2010	Population, jobs, and housing (2010-2030)	Polycentric network of urban areas with development axis
Manchester	2013 Stronger Together / 2009 & Greater Manchester Growth Plan / 2014	Jobs, population, and GVA (Gross Value Added) (2008-2024)	Polycentric network of cities
Dublin	Regional Planning Guidelines for the Greater Dublin Area / 2010	Population and housing (2010-2022)	Polycentric structure with development axis
Zurich	Zurich Strategies 2025 / 2011	No	Integration of the central and surrounding areas

TABLE 1.1 Polycentric development in spatial planning practice: evidence from 50 spatial plans for worldwide metropolitan regions

Note(s): metropolitan areas are sorted by the number of inhabitants in 2010 following the OECD's (2012) delimitation. However, certain discrepancies can be found in this ranking because of the inclusion of some metropolitan areas that are not considered in the OECD's study of 275 metropolitan areas (see OECD, 2012). The metropolitan areas related to these 50 analyzed spatial plans are represented in Figure 1.1 as blue circles.

§ 1.4 General aims and questions

To advance the appeal for metropolitan agglomerations and polycentricity made by planners, geographers, economists, and policymakers, numerous major, interrelated issues demand further attention. In particular, these issues point to the conceptualization of polycentricity, the empirical analysis of the economic, social, and environmental (dis)advantages of polycentricity, and how to interpret the relationship between polycentricity in research and polycentricity in policy.

First, various approaches to polycentricity co-exist without a high level of integration. One approach refers to polycentricity on the intra-urban (Davoudi, 2003) or intra-metropolitan scale (Brezzi and Veneri, 2015; Limtanakool, 2006), whereas another refers to polycentricity on the inter-urban (Davoudi, 2003) or regional scale (Brezzi and Veneri, 2015; Veneri and Burgalassi, 2012). Moreover, when these approaches are integrated, they are often conflated, at least to an extent (Van Meeteren et al., 2015). Therefore, it can be argued that it is essential to reconcile the two approaches to polycentricity to advance the debate on polycentricity's conceptualization and subsequent applicability in planning practice.

POLYCENTRIC DEVELOPMENT / NUMBER OF CENTERS	METHOD OF IDENTIFYING CENTERS	MEASUREMENT OF POLYCENTRICITY	POLYCENTRICITY AND PERFORMANCE
Yes / Inner core of centers and 21 other centers	Not empirical	No	No
Yes / 2 metropolitan, 17 inter-municipal, and 43 municipal centers	Not empirical	No	No
Yes / 6 centrality areas or centers	Not empirical	No	No
Yes / München and 11 regional centers (e.g., Freising)	Not empirical	No	No
Yes / Lisboa and 17 municipalities (e.g., Cascais)	Not empirical	No	No
Yes / Central city and 19 other centers (e.g., Stadlau)	Not empirical	No	No
Yes / Frankfurt and centers in the other 74 municipalities	Not empirical	No	No
Yes / 7 regional centers (e.g., Le pôle Josaphat)	Not empirical	No	No
Yes / Amsterdam and 12 other economic centers	Not empirical	No	No
Yes / 3 international and 10 metropolitan centers (e.g., Delft)	Not empirical	No	No
Yes / 2 regional, 9 town, and 19 district centers	Not empirical	No	It only defines performance indicators
No / 5 'Transit-Oriented Development' areas (e.g., Køge, Hillerød, Helsingør, Roskilde)	No identification of centers	No	No
Yes / Stockholm and 8 other centers (e.g., Flemingsberg)	Not empirical	No	It only defines performance indicators
Yes / Lyon and 33 other centers (e.g., the Chassieu and Genas urban area)	Not empirical	No	No
Yes / Manchester and 11 other regional centers (e.g., Bury)	Not empirical	No	No
Yes / Dublin and 8 other centers (e.g., Tallaght)	Not empirical	No	It only defines performance indicators
No	No identification of centers	No	No

Second, although many claims have been made about the economic, social, and environmental advantages of polycentricity on intra- and inter-urban scales, little has been proven (see, e.g., Burger, 2011; Lee 2006a; Meijers, 2007a). Whereas Meijers and Burger (2010) have revealed, e.g., that polycentric constellations (instead of monocentric ones) are associated with higher labor productivity, Meijers (2008a) and Burger et al. (2014a) have found that they also have fewer cultural and retail amenities. The lack of conclusive results on the role that polycentricity plays in performance highlights the challenge to find a more comprehensive and systematic empirical framework in an attempt to unify the fragmented empirical research on the advantages of polycentricity.

Third, an improved understanding of polycentricity in research to address how polycentric development could be conceptualized in spatial plans and how the assumed benefits of polycentricity can be realized is still missing from current planning practices (see Table 1.1). This issue is of great importance to facilitating a more evidence-informed planning in which polycentricity appears as a bridge-building tool between research (evidence) and policy (spatial plans) with the aim of improving the feasibility and effectiveness of spatial plans' economic, social, and environmental objectives. Therefore, these three issues may stimulate research that links the knowledge of polycentric constellations and their empirically tested implications for economic, social, and environmental aspects to planning practice and policy in metropolitan areas. In short, this is the key motivation for my dissertation.

The overarching research goal of this thesis is to contribute to the debate on polycentricity in the three interrelated issues mentioned above. First, it aims to renew the conceptualization of polycentricity by bringing together two distinct literatures, namely, the literature on intra-urban polycentricity and the literature on inter-urban polycentricity. Second, it aims to empirically substantiate the relationship between polycentricity and performance in metropolitan areas. Third, it aims to understand how the makers of spatial plans have addressed polycentric development and how the assumed benefits of polycentricity can be realized in planning practice. To accomplish these goals, this thesis addresses three general questions:

1. How has the conceptualization of polycentric development in spatial plans evolved over time, and what can be learned from this evolution?
2. How has polycentricity been conceptualized in research, and how can it inform planning practice?
3. To what extent does polycentricity foster better performance in a metropolitan area, and how can its effects be realized in planning practice?

§ 1.5 Single case study: the Barcelona metropolitan region

This dissertation focuses on the metropolitan scale. In theory, two types of explorations could be conducted at this territorial scale to address the research questions set forth above. One exploration has a between-case nature, which draws conclusions based on evidence from cross-study case attributes. The second exploration has a within-case nature, which draws conclusions from the characteristics of a single case study. This thesis is of the latter type—a single case study—because the topic under examination (i.e., the multiple relationships between polycentricity, performance, and planning) is highly dependent on a metropolitan region's contextual conditions and requires an in-depth examination that requires multiple types of methods and data.

Accordingly, one key point is the selection of the single case study based on its degree of representativeness within the population of possible case studies. One relevant population for this dissertation, as shown in Figure 1.1, is that of very important worldwide metropolitan regions, which are used to explore the triple relationship between polycentricity, performance, and planning. In terms of polycentricity, critical and influential cases can be represented by those metropolitan regions that already have a high degree of polycentricity because with regard to the polycentricity debate, they have a great potential to advance learning about the major problems discussed above. With regard to performance, critical and influential cases can be detected from the degree of embeddedness in external global networks (e.g., multinational corporations and air passenger networks) of metropolitan regions. It is known that external linkages between distant metropolitan regions have a great deal of explanatory value for evaluating their performance in accordance with their role as main places, for example, with respect to knowledge-intensive activities (see Burger, 2011; Wall, 2009). In terms of planning, critical and influential cases could be represented by those metropolitan regions (see the blue nodes in Figure 1.1) that have a recent spatial plan aimed at implementing a polycentric development strategy, as analyzed in Table 1.1.

The case study of this thesis is the Barcelona metropolitan region because it has the key characteristics that, as discussed above, are found in a critical and influential case study. Barcelona is one of the world's most polycentric metropolitan areas. More specifically, the Barcelona metropolitan region is the seventh-most polycentric metropolitan area in the world, according to the OECD (2012). Moreover, its recent spatial plan aimed at implementing a polycentric development policy, the 2010

Barcelona Metropolitan Territorial Plan, reflects Catalonia's strong historical tradition, thus enabling the study of transition patterns in the conceptualization of polycentric development in planning over time. Indeed, the 1966 Director Scheme for the Barcelona Metropolitan Area was one of the first spatial plans—together with the 1961 Washington Plan (known as the "Year 2000" plan), the 1963 Milan Inter-Municipal Plan, the 1965 Director Scheme for Urban Planning and Development for the Paris Region, and the 1966 Plan for the Stockholm Region—to break with the then-popular concentric model of green belts and satellite cities and to propose networked, polycentric spatial configurations to resolve the pressure of urbanization on metropolitan regions' central cities. Furthermore, Barcelona could play a central role in globalization processes, for example, because of its high degree of centrality in relation to the international air passenger network. More specifically, as shown in Figure 1.1, in 2012 Barcelona was ranked the world's nineteenth most central metropolitan area in terms of air passenger flows between airports. Although the centrality of Barcelona to the international air network is not a sufficient basis to conclude that the Barcelona metropolitan region is a critical and influential case study for exploring performance, it may reveal that the Barcelona metropolitan region could also be well positioned in other external global networks. Therefore, it can be argued that the single case study of the Barcelona metropolitan region could serve as an example for other metropolitan regions because of its learning potential in terms of polycentricity, planning and (in a sense) performance.

The Barcelona metropolitan region is the primary urban agglomeration of Catalonia, which is an autonomous region of 7.5 million inhabitants located in Spain. Catalonia's GDP ($314 billion) exceeds those of Portugal and Hong Kong, and its per capita GDP of $35,000 is greater, for instance, than those of South Korea and Italy (Harvard Political Review, 2014). In light of these economic indicators, it is unsurprising that Catalonia can be perceived as one of Spain's economic engines: it accounts for approximately 20 percent of Spain's total GDP, contributes approximately 25 percent of the central government's tax revenue and is responsible for 35 percent of Spain's exports, including 45 percent of its high-tech exports (ibid, 2nd section).

The Barcelona metropolitan region, as shown in Figure 1.2, is composed of the territory previously delimited by the Director Scheme of the Barcelona Metropolitan Area back in 1966; however, it was not until 2010, with the approval of the Barcelona Metropolitan Territorial Plan, that this metropolitan delimitation was endowed with a legal framework for planning. The area is composed of seven regions (*comarques*): Alt Penedès, el Baix Llobregat, el Barcelonès, el Garraf, el Maresme, el Vallès Occidental, and el Vallès Oriental. Today, the Barcelona metropolitan region has approximately 5 million inhabitants, representing more than 65 percent of Catalonia's population. Moreover, it is the second-densest metropolitan area and has the sixth-highest population and the tenth-highest GDP in Europe (OECD, 2012). The remainder of the most important information about the Barcelona metropolitan region, including the names of places and infrastructure networks, will appear in subsequent chapters of this thesis and in Figure 1.2.

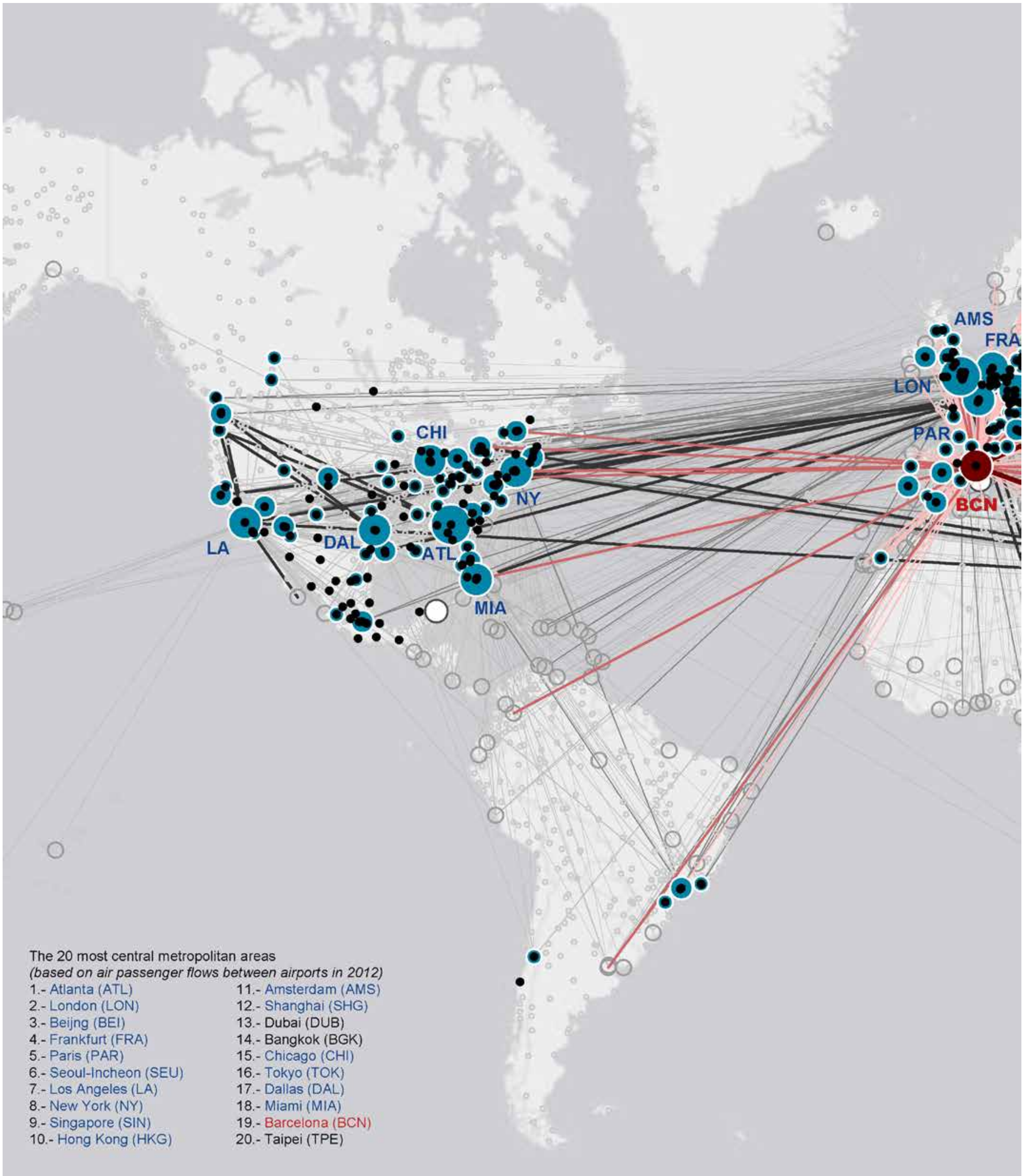

FIGURE 1.1 Worldwide metropolitan regions with a prime importance to the link between polycentricity, performance and planning

Note(s): the size of the nodes indicates the degree of centrality of the metropolitan areas within the international air passenger network, whereas the dark point represents either the 275 metropolitan areas identified by OECD (2012) or those that have a spatial plan (e.g., Sydney and Hong Kong) with a polycentric development policy in accordance with Table 1.1. Barcelona, the case studied in this thesis, is represented in red. The thickness of the flow represents the strength of the interaction among metropolitan areas in terms of passenger flows. Only the flows generated by the 20 most central airports are presented to facilitate the visualization and interpretation of the air passenger networks.
Source: own elaboration based on 2012 OpenFlights airport, airline and route databases (see http://openflights.org/data.html).


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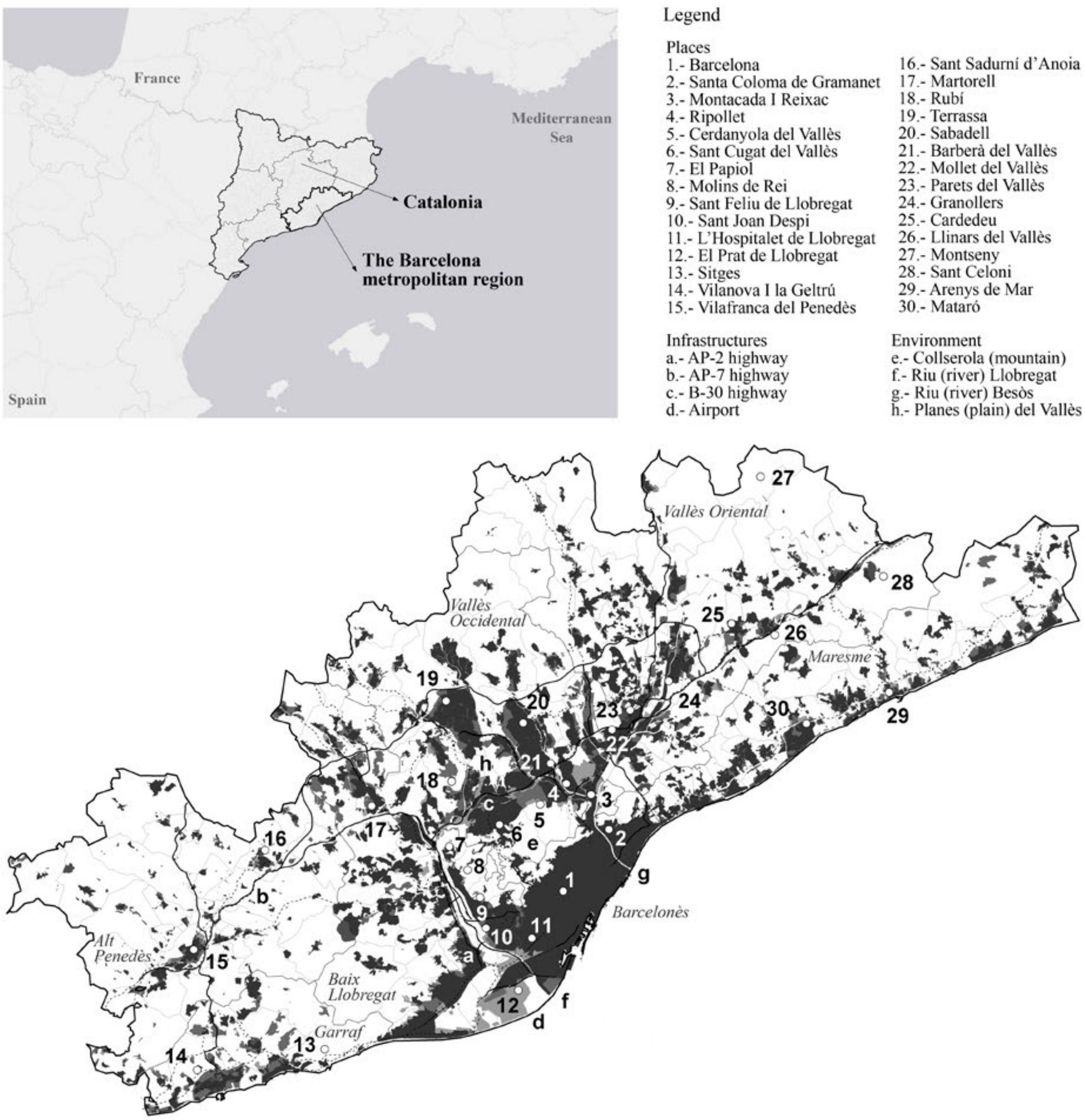


FIGURE 1.2 Single case study: the Barcelona metropolitan region in Catalonia

§ 1.6 Organization of the thesis

The organization of this thesis, as shown in Figure 1.3, has five parts. The first part, which consists of two chapters (chapters 1 and 2), presents the introduction to the current debate on polycentric urban systems and the research framework, both of which guide the direction of this dissertation. The fifth part, which consists of one chapter (chapter 9), presents both conclusions and a research and policy agenda for the triple Ps: polycentricity, performance, and planning. Each of the other three parts refers to a different aspect of the triangular relationship between polycentricity, performance, and planning, which together encompass the threefold goal of this thesis. The three general research questions (see section 1.2) are addressed in 6 chapters distributed among these three core parts. Answering the general research questions requires the formulation of specific research questions that consider the single case study of the Barcelona metropolitan region. These research questions are related to a different challenge or research gap that arises out of a review of the state of the art on polycentricity. The review of the polycentricity literature, the more detailed identification of the challenges and research gaps, and the elaboration of more-specific questions and a research approach to answer them are presented in chapter 2. It should be noted that although some chapters could simultaneously contribute to more than one of these parts—e.g., addressing the evidence of polycentricity on performance is also aimed at defining planning policies—their fundamental aim certainly is close to one of the three blocks mentioned above.

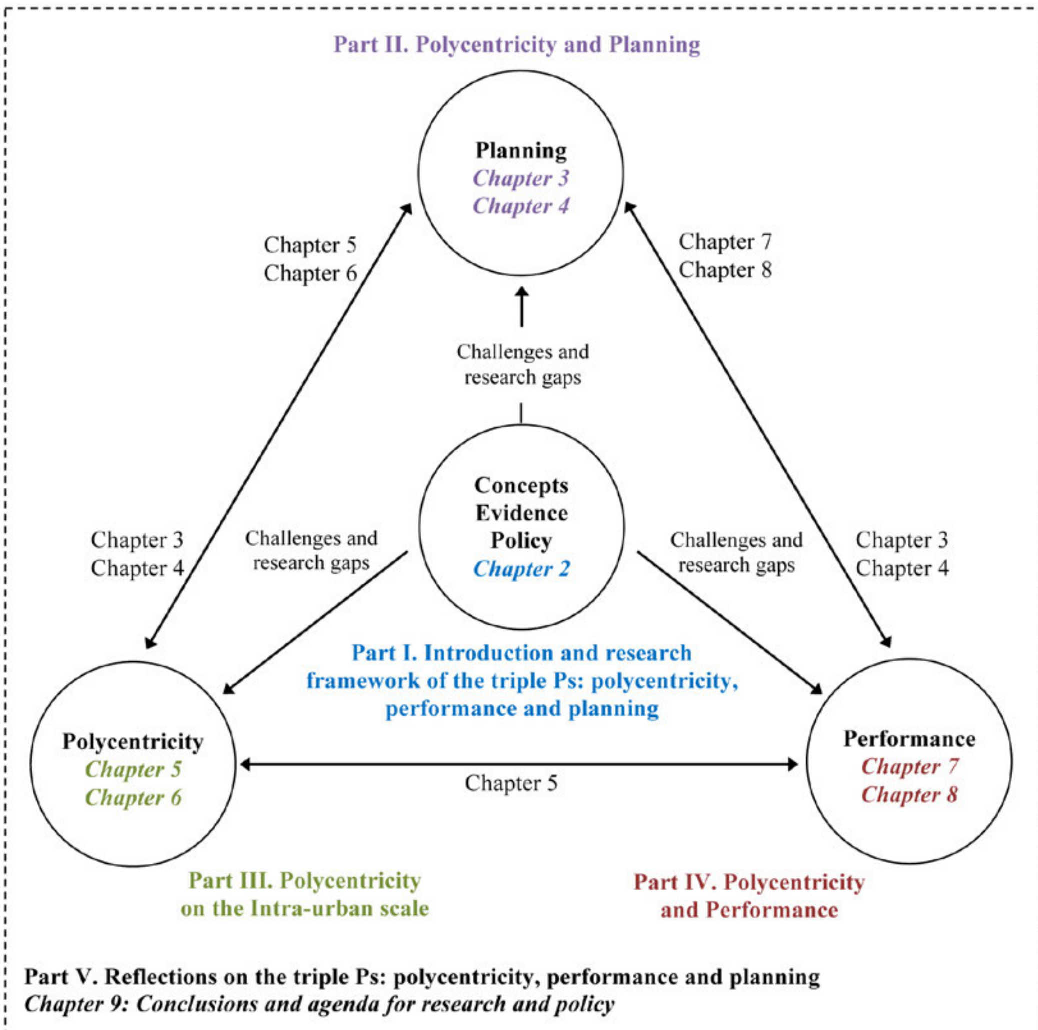


FIGURE 1.3 Schematic overview of the organization of this thesis

The second part (Polycentricity and Planning) contains 2 chapters that contribute to an understanding of how the makers of spatial plans have addressed polycentric development. Chapter 3 studies the planning proposals for Barcelona and Catalonia and the territorial model that they advocated to reveal transition patterns in the conceptualization of polycentric development in successive spatial plans. Chapter 4, in turn, scrutinizes the last approved spatial plan for the Barcelona metropolitan region, the 2010 Barcelona Metropolitan Territorial Plan to bring forward complementary arguments to the discussion about whether a polycentric model is to be preferred over alternative territorial models. Moreover, the findings of these two chapters provides interesting lessons on how the understanding of polycentric development in planning is addressing the ongoing academic debate on polycentricity and its link to the performance of metropolitan areas (see Figure 1.3).

The third part (Polycentricity on the Intra-urban Scale) contains 2 chapters that aim to renew the conceptualization of polycentricity by bringing together two distinct literatures, namely, the literature on intra-urban polycentricity and the literature on inter-urban polycentricity. Chapter 5 proposes a novel methodology to identify centers in metropolitan areas by considering different pathways to polycentricity that have not yet been very integrated—specifically, the decentralization and the incorporation-fusion trajectories. Moreover, this chapter sheds light on the most appropriate approach to identifying centers in a manner that defines the polycentric model in the Barcelona metropolitan region, thus enabling a subsequent examination of the link between polycentricity and performance in that metropolitan region (see Figure 1.3). Chapter 6 quantifies the internal metropolitan spatial structure of Barcelona and its development by incorporating distinct approaches—as traditionally created by the inter-urban polycentricity literature—to measuring the degree of polycentricity. The results of this chapter will also stimulate further discussion of how polycentric development policies can improve their effectiveness and feasibility in spatial plans (see Figure 1.3).

The fourth part (Polycentricity and Performance) contains 2 chapters that explicitly contribute to empirically substantiating the relationship between polycentricity and the performance of metropolitan areas. Both chapters examine whether the agglomeration benefits that are available in a polycentric metropolitan area lead to a more social and environmental mobility pattern in the Barcelona metropolitan region. Whereas chapter 7 focuses on the co-location of jobs, urban amenities and households, along with people’s choice of travel mode for both work- and non-work-related travel, chapter 8 focuses on travel behavior externalities, particularly with respect to not only trip distance and travel time but also the per capita CO_2 emissions attributable to transportation. The findings of these two chapters are also expected to shed more light on how the benefits of polycentricity can be realized in planning practice (see Figure 1.3).

2 State of the art on polycentricity in the literature: concepts, evidence and policy

§ 2.1 Introduction

The aim of this chapter is to deepen the understanding of the current debate in the literature on polycentricity; that debate will guide the direction of this research. Embedded into the study of the triangular relationship among polycentricity, performance, and planning, this chapter identifies challenges and research gaps to formulate specific research questions that answer the three general research questions articulated in section 1.2. In elaborating a framework for an improved knowledge of polycentricity, this chapter builds upon three aspects in the existing literature: concepts, evidence, and policy. However, some of the associations between polycentricity, performance, and planning that this research aims to address—e.g., how polycentric development is conceptualized in spatial plans or how to comprehensively and systematically measure polycentricity to examine its effects on metropolitan performance—have been studied much less frequently. Accordingly, this chapter also discusses a conceptual framework that departs from the literature's current knowledge to enable further development and empirical exploration in the remainder of this thesis.

The rest of the chapter is organized as follows. Section 2.2 discusses the concept of polycentricity by focusing not only on its meanings related to distinct territorial scales but also on its measurement associated with different dimensions. Section 2.3 presents the conceptual approach to the study of polycentricity and how it is linked to performance; it also discusses the empirical evidence for this relationship. Section 2.4 elaborates the interplay between polycentricity and planning with regard to the expectations and issues that arise out of their relationship. Section 2.5 describes the research approach to answering the specific research questions that arise out of the challenges and research gaps identified in the previous sections and that address the three general, overarching research questions. Additionally, this section contains a brief description of the methods and data used to conduct the research.

§ 2.2 The concept of polycentricity

The manner in which polycentricity is conceptualized in academic discourses and policy practice (see chapter 1) raised two types of important questions. First, the concept has different meanings depending on what spatial (territorial) scale is defined. Second, the concept of polycentricity incorporates both a morphological and a functional dimension, which translates into different approaches to measure the extent to which an urban system is or has become polycentric. Whereas the morphological dimension of polycentricity considers places' urban attributes, the functional dimension examines the interactions among them.

Polycentricity on different spatial scales

One common approach is to distinguish among polycentricity on the intra-urban, inter-urban, and inter-regional scales (Davoudi, 2003), as shown in Figure 2.1[1]. Polycentricity on the intra-urban scale refers to the appearance and identification of centers in metropolitan areas that once were monocentric and have evolved into a more polycentric structure by following one of two trajectories. The first pathway is described by the polycentric models of the New Urban Economics theory, which reformulated the monocentric model (Alonso, 1964; Muth, 1969; Mills, 1972) by introducing agglomeration costs as decentralization forces to explain the substantial concentration of office, retail, and (often) residential functions in suburban zones, forming multiple centers. Polycentric New Urban Economics models (e.g., Fujita and Owaga, 1982; Fujita et al., 1997; White, 1999) also influenced the appearance of several methods to identify the emerged suburban areas of metropolitan areas, which had already begun to develop agglomeration economies of sufficient power to attract populations and the types of jobs and functions heretofore found exclusively in the old central city. For example, a US-based body of literature on center identification appeared in the late 1980s that confirmed the existence of polycentric structures in North American metropolitan areas in general by using distinct function forms of employment density as a proxy for examining the spread of agglomeration economies over the metropolitan area (e.g., McDonald and Prather, 1994; McMillen, 2001b).

A second pathway is presented by the theoretical models of the New Economic Geography (Fujita and Mori, 1997; Fujita et al., 1999a, 1999b). These models explain the monocentric-to-polycentric transition through changes in the urban hierarchy and spatial location of cities as a consequence of the interplay between agglomeration economies and agglomeration diseconomies. Polycentric New Economic Geography models therefore seek to explain the formation of polycentric structures through the growing interaction between centers and their covered market areas, which in turn led to the functional integration of similarly or differently rank cities in a metropolitan area. This close attention that the New Economic Geography paid to the hierarchy and functional relationships among centers has contributed to the rise of a Europe-based literature to identify centers in metropolitan areas since the mid-1990s (e.g., Clark and Kuijpers-Linde, 1994; Aguilera, 2005; Veneri, 2010a). The fact that the evolving European urban systems have often been characterized by a long-term functional integration process (with respect to the incorporation or fusion of formerly distinct cities (Champion, 2001)) could explain why in most cases, this Europe-based literature has identified centers by addressing the functional relationships between cities, not the degree of employment density.

However, the empirical findings from numerous case studies in North America (Anas et al., 1998) and Europe (Bontje and Burdack, 2005; Hohenberg and Lees, 1995) that focus on explaining the internal urban spatial structure of metropolitan areas have revealed that both trajectories to polycentricity exist on both sides of the Atlantic. These findings highlight that not all of North America's centers—which traditionally have earned the appellation of 'edge cities' (Garreau, 1991) or 'subcenters' (Gordon and Richardson, 1996)—are the result of decentralization trends, nor are all of the centers in European urban systems composed of centers that have been incorporated or fused into a metropolitan area. For example, Anas et al. (1998) observe the existence of two types of 'subcenters' in North American metropolitan areas, one that is related to older cities that have been increasingly incorporated into a metropolitan area and another that refers to new 'subcenters' appearing at the nodes of a transportation network. Bontje and Burdack (2005) state that recent development trends in

1 Although the most common distinction among polycentricity on various territorial scales is that proposed by Davoudi (2003), other names have appeared in the literature in reference to the intra-urban and inter-urban scales. Whereas the intra-urban scale is also referred to as either the metropolitan (e.g., Veneri and Burgalassi, 2012; Brezzi and Veneri, 2015) or the intra-metropolitan scale (e.g., Limtanakool, 2006), the inter-urban scale has also earned the appellation of either the inter-metropolitan (e.g., Limtanakool, 2006) or the regional scale (e.g., Veneri and Burgalassi, 2012; Brezzi and Veneri, 2015).

European metropolitan regions (e.g., the Amsterdam South Axis) resemble the concept of 'edge cities' in urban functions, their size in terms of employment, and their development patterns.

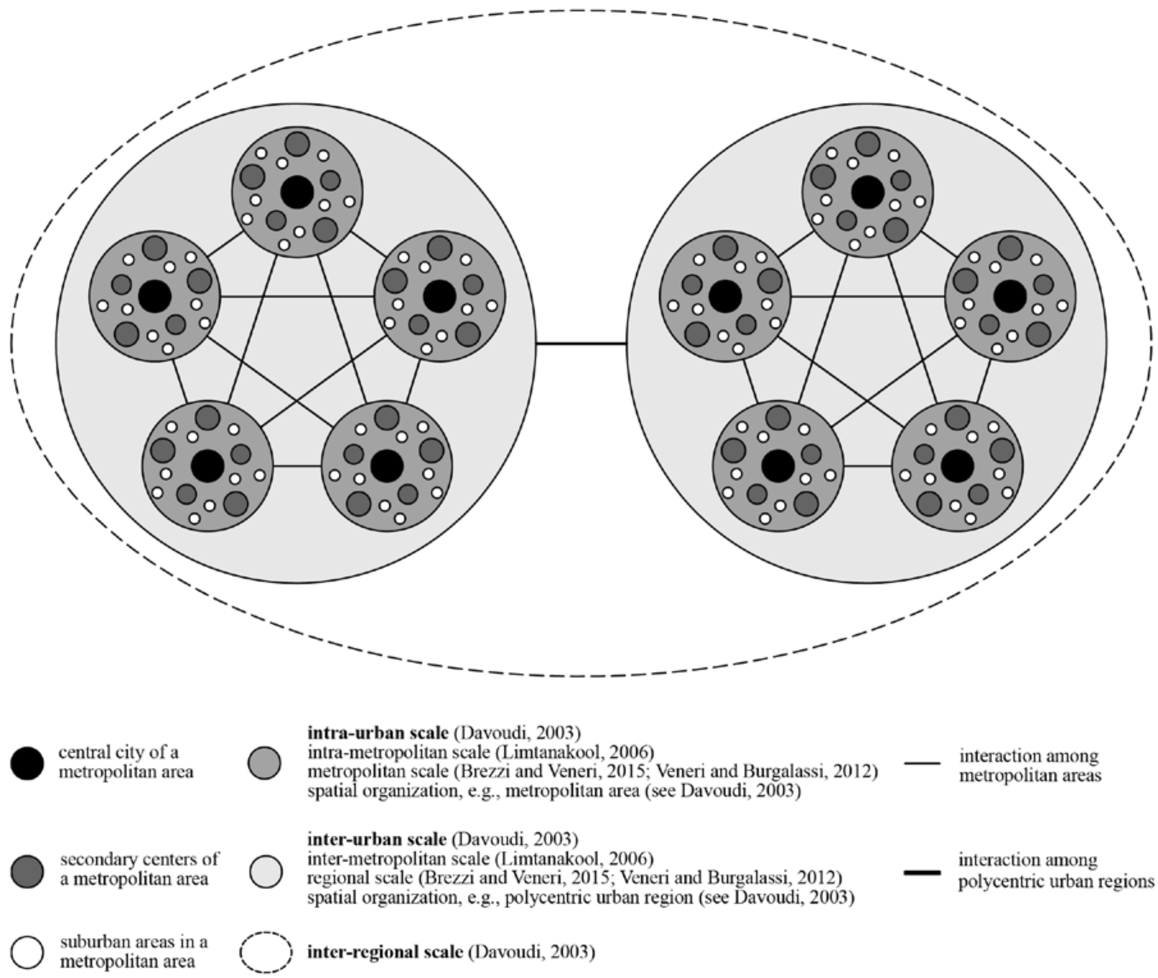


FIGURE 2.1 Schematic conceptualization of polycentricity on different spatial scales

Own elaboration building upon the contributions of Davoudi (2003:980-987), Limtanakool (2006:17-21), Veneri and Burgalassi (2012:1019-1020), and Brezzi and Veneri (2015:1131-1134).

The concept of polycentricity can also be defined in terms of higher spatial scales, namely, on inter-urban and inter-regional scales (Davoudi, 2003), as Figure 2.1 shows. A paradigmatic example of polycentricity conceptualized on an inter-urban scale is the analytical concept of the polycentric urban region (Kloosterman and Musterd 2001; Parr, 2004) introduced in the late 1990s. In Europe, examples of polycentric urban regions have been gradually identified and empirically studied—for example, the Randstad-Holland, the Flemish Diamond, and the Rhine-Ruhr (see Burger, 2011; Lambregts, 2009; Meijers, 2007a)—and to a lesser extent in Japan (Kansai), as Batten (1995) highlights. The primary distinction between the concept of polycentricity on this scale compared to the intra-urban scale is that whereas the latter refers to the development of a polycentric structure in a metropolitan area that could have coherently extended its area of influence over time, the former refers to the rise of polycentricity caused primarily by the functional integration of historically separate urban regions. For instance, Burger (2011:25) defines the rise of polycentricity related to the concept of polycentric urban regions as follows: "*at the regional level, planners have developed the concept of the polycentric urban region, which is a set of historically and spatially separate city-regions comprising a larger functional urban region*". Therefore, it can be argued that the dominant pathway to polycentricity in polycentric urban regions is the fusion mode, not the decentralization mode (Champion, 2001) because its conceptualization is primarily based on the fusion of historically distinct city-regions into a larger urban region because of the considerable spatial interaction and specialized economic profiles of its constituent adjacent city-regions (Kloosterman and Musterd, 2001; Parr, 2004).

In addition, the conceptualization of polycentricity on an inter-urban scale adds complexity to the already fuzzy concept of polycentricity. Theoretically, an urban system that may be polycentric on one scale—for example, at the level of the polycentric urban region—may be monocentric on another scale—for example, on the intra-urban level (Burger, 2011; Hall and Pain, 2006). For instance, a polycentric urban region can be polycentric on an inter-urban scale because it has no obviously leading center (e.g., the Randstad region's cities of Amsterdam, Rotterdam, Den Haag, and Utrecht), whereas it can be monocentric on an intra-urban scale because of the prominent role played by the main center of each city-region (e.g., Amsterdam). Perhaps as a result of this fact—and because the polycentric urban region is conceptualized as a planning concept—the current literature on polycentric urban regions has not empirically identified centers on these two territorial scales. Instead, the literature has provided a definition based on the morphological attributes and functional relationships between the major city of each city-region (e.g., Amsterdam, Rotterdam, Den Haag, and Utrecht) within a polycentric urban region.

Other, more recent applications of the conceptualization of polycentricity on an inter-urban scale can be found—for example, in those studies that have used certain regional territorial delimitations such as functionally coherent regions in the Netherlands (Burger and Meijers, 2012; Meijers, 2008a) or NUTS-2 regions in Italy (Veneri and Burgalassi, 2012). The reason that these studies used the aforementioned territorial delimitations is that like a polycentric urban region, their extensive territorial scales can allocate historically separate city-regions that comprise a larger urban region in which the important functional relationships between them arise.

The inter-regional scale is the most extensive scale upon which polycentricity has been conceptualized in the literature (Davoudi, 2003); except for its size, the inter-regional scale is essentially the same as the inter-urban scale. Early examples of this phenomenon are the concepts of 'megalopolis' (Gottmann, 1957, 1961) and 'urban fields' (Friedmann and Miller, 1965). Examples that are recent include the discussion of the polycentric European configuration that the literature refers to as the 'Pentagon' (EC, 1999) and the debate about megaregions, for example, in the US (Dablanc and Ross, 2012; Ross, 2009) and the Pearl River Delta (Li et al., 2013). Finally, because of the size of polycentric urban configurations on the inter-regional scale, a complementary body of literature has also referred to this scale as international (e.g., NORDREGIO, 2005; Vandermotten et al., 2008; Waterhout et al., 2005). However, that body of literature conceptualizes polycentricity as a key normative policy to be achieved, not as an urban system to be defined. One example of this approach is the 1999 European Spatial Development Perspective (see EC, 1999), which that advocated for polycentric development across European countries both to reduce disparities and to enhance competitiveness (Meijers, 2008b; Waterhout et al., 2005); an example that is more recent is the discussion of polycentric systems across OECD countries (Brezzi and Veneri, 2015).

Measurement

As discussed above, conceptualizations of polycentricity have led to attempts to quantify polycentricity. Most of these efforts address the inter-urban scale, whereas less attention has been paid to measuring polycentricity on the intra-urban and inter-regional scales. In general, there seems to be an agreement that polycentricity has both morphological and functional dimensions, both of which emerge in the approaches to its measurement.

The morphological dimension is generally measured by examining the spatial distribution of characteristics such as employment or population over centers that comprise the urban system. On the intra-urban scale, the measurement of morphological polycentricity has traditionally been related to decentralization-concentration patterns of employment (Anas et al., 1998). The decentralization pattern of employment has been explored by estimating a polycentric model to analyze how the density gradient associated with centers has changed over time (e.g., McMillen and Lester, 2003; Sun et al., 2012). Frequently, the concentration pattern of employment has been studied through either an analysis of absolute and relative job growth in centers relative to the remainder of the metropolitan area or the use of spatial concentration indicators such as location quotients and Gini coefficients (e.g., Lee, 2006a; Lee and Gordon, 2007). Therefore, a joint interpretation of both patterns is required to shed light on whether urban systems have evolved into a more polycentric spatial form: e.g., the flatter slope of the density gradient associated with a metropolitan area's central city combined with larger employment growth in centers illustrates a process of concentrated decentralization around centers and thus, a metropolitan pattern that is more polycentric than scattered.

On the inter-urban and -regional scales, morphological polycentricity has been analyzed in reference to the existence of (or a lack of) hierarchy among centers. This lack of hierarchy has been conceptualized as a balanced distribution with respect to the absolute importance of centers. Frequently, rank-size distribution indices of population (e.g., Hall and Pain, 2006; Meijers, 2008b) or employment (e.g., Burger and Meijers, 2012) have been employed to assess (a lack of) hierarchy. Occasionally, however, primacy indicators have also been adopted (Burger et al., 2011; Veneri and Burgalassi, 2011).

The measurement of the functional dimension of polycentricity concentrates on the balance in the distribution of flows and the level of spatial integration among centers on the inter-urban scale (Burger and Meijers, 2012; Burger et al., 2011; De Goei et al., 2010)—or, less frequently, on the inter-regional scale (e.g., Taylor et al., 2008). With regard to the distribution of flows, the direction of the linkages among centers has become the key point of the analysis. An equal balance in the distribution of flows among centers means that functional relationships are not directed at one center; instead, two-way flows among centers are present, thus indicating polycentricity. Several empirical approaches have been developed, but the usage of different centrality measures (Burger and Meijers, 2012; Burger et al., 2011; Hall and Pain, 2006; Limtanakool, 2006; Van der Laan, 1998) is the most common proxy to examine the balance in the direction of flows among centers. In contrast, the concept of spatial integration has been associated not only with the strength of the functional linkages among centers but also with the extent to which the centers are functionally interdependent within an urban system. In a hypothetical polycentric system that is fully spatially integrated, actual flows among centers do not differ significantly from total potential flows. Using a network density indicator (e.g., Burger and Meijers, 2012; Burger et al., 2011; Green, 2007) or estimating a gravity model (e.g., De Goei et al., 2010; Van Oort et al., 2010) to focus on interdependencies among urban areas enables study of the strength of integration.

Challenges and research gaps

The increasing amount of literature aimed at conceptualizing and measuring polycentricity has contributed to our understanding (from both a morphological and a functional perspective) that polycentric urban forms are on the rise on multiple territorial scales. However, the diverging theoretical approaches rooted in different disciplines, along with the varied conceptual interpretations and empirical approaches, all vie with each other for recognition in the study of polycentricity, a situation that adds to the fuzziness of the concept. The different literatures have co-existed without a great deal of integration; when they become integrated, they often become conflated to some extent (Van Meeteren et al., 2015). Therefore, it can be argued that there is a need to integrate these different literatures. This thesis aims to do so because integration is essential to achieving the other objective of exploring the empirical underpinning of assumptions about the link between polycentricity and performance. In light of this call for more conceptual clarity on polycentricity, the intra-urban scale not only is experiencing challenges but is also the subject of research gaps.

With regard to the conceptualization of polycentricity, the differences in the empirical approaches of the literature on identifying centers in metropolitan areas could imply that there is room for improvement. The US-based literature identifies centers by analyzing the spread of employment to fit in with the decentralization trajectory toward polycentricity, whereas the Europe-based literature identifies centers by addressing the functional relationships that satisfy the incorporation-fusion trajectory toward polycentricity, part of the conceptual renewal of polycentricity involves bringing these streams together. In practice, centers in metropolitan areas, as discussed above, arise out of both decentralization and incorporation-fusion processes; therefore, ignoring one of these mechanisms would therefore describe an incomplete reality of contemporary metropolitan areas.

The literature on the measurement of polycentricity is continuously extending. Novel contributions to the polycentricity literature on an inter-urban scale have recently argued, for example, that the measurement of functional polycentricity is likely to be biased if the multiplexity of flows and individual-level heterogeneity are not considered (Burger et al., 2014b; Burger et al., 2014c). Of course, if functional polycentricity is derived from flows between places, then the level of functional polycentricity may vary when different types of flows (e.g., commuting, business trips, shopping, leisure trips, etc.) are considered ('multiplexity'). Additionally, the existence of individual-level heterogeneity implies that even a similar type of flow may vary according to individual characteristics such as age, sex, educational level, etc. ('individual-level heterogeneity'). However, a broader analysis of functional polycentricity that accounts for both multiplexity and individual-level heterogeneity, as suggested by Burger et al. (2014b, 2014c), is still missing on an intra-urban scale, and it deserves further development on an inter-urban scale. Furthermore, from this dissertation's perspective, the literature on the complementarity of urban systems (e.g., Meijers, 2005; Meijers, 2007b) merits being added as a third dimension of functional polycentricity. Therefore, research aimed at reaching broader conclusions about the existence of polycentricity should also not only examine complementarity (together with the distribution of flows and spatial integration) but also quantify the degree of morphological polycentricity. The point is that several studies have stressed that one defining feature of a polycentric urban system is the existence of a minimum degree of complementarity among centers (Champion, 2001; Parr, 2004).

In addition, it can be argued that by taking into account the relationship between metropolitan structure and the conceptions of the regional economy (i.e., occupations and sectors), the meaning of morphological and functional polycentricity can be better understood. For example, much more than in the past, complementarity should be measured based on 'what people do' (occupations) instead of 'where people work' (sectors). The reason is that today, because of the growing appreciation for the contribution of human capital to economic development, the performance of the regional economy has become much more dependent on a mix of knowledge-based occupations instead of a mix of industrial sectors (Markusen, 2004; Markusen and Schrock, 2006; Thompson and Thompson, 1985). Because of the complex interaction among polycentricity, performance, and planning, further elaboration of these challenges will be provided in the discussions contained in the next two sections.

§ 2.3 Polycentricity and performance

Another subject of interest in the ongoing debate about polycentricity concerns the extent to which a polycentric spatial configuration is preferable to a monocentric one, which relates to the extent to which both configurations can be associated with economic, social, and environmental (dis) advantages. A common theoretical proposition advanced by several New Urban Economics models of cities that include 'subcenters' (e.g., Anas and Kim, 1996; Fujita and Owaga, 1982; Fujita et al., 1997; Sasaki and Mun, 1996; White, 1999) is that the appearance of multiple centers in a metropolitan area can result in important competitive advantages. One explanation is that agglomeration diseconomies that emerge in a monocentric metropolitan area with a single center—e.g., pollution, congestion, high land prices, and commuting costs—are mitigated, whereas firms and households can continue to benefit from the agglomeration benefits that arise out of the presence of several centers—e.g., greater productivity, more innovative opportunities for firms and more chance for both firms and people to learn and acquire skills. For instance, building upon the contributions of the polycentric New Urban Economics models, McMillen (2004:255) stresses that "*large subcenters can look remarkably similar to a traditional central business district, with thousands of workers employed in a wide variety of industries. A polycentric city—a metropolitan area with a strong central business district and large subcenters—can potentially combine the advantages of the traditional monocentric city and a decentralized spatial form. Large subcenters offer agglomeration economies to firms, while potentially reducing the long and time-consuming commute of a monocentric city*".

The claim about the advantages of polycentricity still requires broad testing, and the literature lacks a conceptual framework to link polycentricity on an intra-urban scale and metropolitan performance. That said, one important and obvious premise can be derived. Regardless of whether there is a relationship between polycentricity and a metropolitan area's improved performance, this association should be conceptualized through theories of agglomeration. Indeed, the excellent survey of theoretical and empirical polycentric models carried out by Anas et al. (1998:1455) reveals that the formation of centers is closely linked to agglomeration economies: "*urban subcenters, like cities themselves, are formed from the tension between agglomerative and dispersive forces. Both sets of forces entail strong externalities—external economies producing the agglomerative tendencies, and congestion or nuisance externalities limiting the size and density of the agglomeration that is achieved*". The remainder of this section explains the existing knowledge of the link between polycentricity and theories of agglomeration, on the one hand, and the current empirical evidence on polycentricity and performance, on the other hand, to create an empirical framework that is more comprehensive and systematic to examine the effects of polycentricity on the intra-urban scale.

Concepts: polycentricity and theories of agglomeration

The study of agglomeration economies in urban economics has generally focused on a single bounded agglomeration or city, where size and density have been conceptualized as a key determinants of the presence of a range of agglomeration economies. However, in his seminal work entitled 'The Economies of Urban Size', Alonso (1971) asks 'how big is too big' and 'how big is big enough' to address the urban benefits and costs associated with agglomeration economies as urban size increases.

With respect to urban benefits, there is a body of literature that has identified the role played by agglomeration economies as important sources of both productivity (Ciccone, 2002; Ciccone and Hall, 1996) and income per capita (Glaeser and Gottlieb, 2009; Glaeser and Mare, 2001). Other studies have stated that the larger the urban agglomeration, the greater the opportunities enjoyed by firms for more innovative processes (Porter, 2000) and the higher the propensity to exchange ideas, knowledge, and social interactions between firms and people (Rosenthal and Strange, 2004). The remainder of a large city's benefits have been associated with a greater access to jobs (Anas et al., 1998) and urban amenities such as health services (hospitals), educational services (universities and schools), cultural and leisure services (museums, theatres), other consumer amenities (Clark et al., 2002; Glaeser et al., 2001), and even higher quality of life (Quigley, 1998). However, large cities can also experience agglomeration costs, which can diminish and even significantly counterbalance the benefits of agglomeration when those cities exceed 'their optimal size' (Capello and Camagni, 2000). The negative externalities of urban size include congestion, which may result in longer trip distances and travel times for households (Gordon et al., 1989a, 1989b, 1991; McMillen and Smith, 2003); increased pollution (Richardson, 1972); and higher land rents (White, 1999) and housing prices (Jeanty et al., 2010).

A metropolitan area's transition into a polycentric structure raises the question of whether agglomeration economies—as compared to a single center or an agglomeration—can be exploited and developed in a set of centers (see, e.g., Anas et al., 1998). This question enables us to link polycentricity and performance based on two well-known scopes of agglomeration economies that have been widely discussed in the urban economics literature: the industrial scope and the geographic scope (see, e.g., Rosenthal and Strange, 2004). More recently, Camagni and Capello (2015) have added the macro-territorial scope; although that scope is not geographically limited to a metropolitan area—it can be related to more than one worldwide city-region—a consideration of the macro-territorial scope may also provide more comprehensive knowledge of the development of agglomeration economies in a metropolitan area.

The industrial scope of agglomeration economies has been related to the literature's distinction between the relative importance of localization versus urbanization economies. This distinction is rooted in the theoretical and empirical discussions of whether agglomeration economies are more closely associated with the increasing economies of scale in industry-specific localization economies, (also called Marshall-Arrow-Romer scale economies, Marshall, 1920) or with the diversification among industries located in a city (also called urbanization economies (Jacobs, 1969)). In other words, the literature questions whether agglomeration economies are related to an industry's concentration (localization economies) or to the size of a city itself (urbanization economies). No consensus, however, has been achieved about whether localization economies or urbanization economies are better for helping a single center increase its performance (see, e.g., Glaeser et al., 1992; Henderson et al., 1995).

In contrast, a polycentric metropolitan area has often been perceived as an interesting economic environment for firms because of the multiple types of agglomeration economies (localization and urbanization economies) that co-exist in distinct centers and the areas between them (e.g., Duranton and Puga, 2005), thus providing firms with an added competitive advantage. For instance, Duranton and Puga (2001) argue that firms can benefit from an urban environment in which specialized (localization economies) and diversified (urbanization economies) centers co-exist because they first may locate in a diversified center, which acts as a nursery, facilitating their share of services and infrastructures with other (non-industry-specific) firms until they find their ideal production process. Then, such firms relocate to a specialized center both to avoid higher production costs and to begin mass production. Parr (2002, 2004), in turn, adds another two advantages: the first is related to inter-industry linkages and the second is related to firms' complexity. Although the first type of advantage is related to the multi- or sequential process of production, which involves several centers that assemble the final product, the second type of advantage is associated with opportunities for firms located at several centers to share transport and transaction costs. In addition, the literature on the formation and identification of centers (e.g., Anas et al., 1998; McMillen and McDonald, 1998a) references additional social and environmental advantages that are related to the presence of multiple types of agglomeration economies in a metropolitan area. In particular, this body of literature suggested that a center's developmental trajectory appears linked to a dominance of either urbanization economies (i.e., a large center that is incorporated into or fused to an expanding metropolitan area) or localization economies (in centers originating from decentralization). For example, McMillen (2001a:1) stresses the assumed positive effects of large centers on public transportation: "*public transportation can be designed to serve subcenters. Buses can help alleviate severe congestion, and commuter rail lines may be able to serve large subcenters. Large subcenters may have enough jobs to warrant designing public transportation that brings central city workers to suburban job locations, which can help alleviate problems of a spatial mismatch between jobs and central city workers*".

The geographic scope of agglomeration economies has been associated with the physical distance at which agglomeration economies have the ability to exert their effects. This scope of agglomeration economies may explain why firms and households located close to the centers of a polycentric metropolitan area receive more benefits than firms and households located further away from those centers. Indeed, the literature that aims to identify centers in contemporary metropolitan areas argues that to verify the existence of a polycentric model, one must examine whether the level of agglomeration economies experiences a distance-decay effect as proximity to the identified centers decreases—in other words, if the agglomeration benefits related to centers are attenuated by distance (see, e.g., McDonald and Prather, 1994; McMillen and Lester, 2003). Moreover, in this body of literature, the theory of agglomeration is almost entirely concerned with density (see Rosenthal and Strange, 2004); therefore, it has frequently used employment density as a proxy for examining the attenuation of agglomeration economies.

In the context of the geographic scope of agglomeration economies, it is also worth mentioning the novel reinterpretation of a complementary body of literature (Burger et al., 2015; Meijers, 2015) on Alonso's (1973:200) concept of 'borrowed size', which enables a link between performance and polycentricity on an inter-urban scale. This concept theorizes the situation in which small cities that are in close proximity to a larger city have some characteristics that are typically exclusive to larger cities (e.g., high-order amenities) because small cities can take advantage of nearby larger cities. Thus, Alonso suggests that small cities were able to achieve some of the (previously discussed) agglomeration benefits related to the urban size of a large city by 'borrowing' the size of their larger neighbors, while avoiding the agglomeration costs associated with a single large agglomeration (Burger et al., 2015). However, being located close to a larger city may imply being located in that city's 'agglomeration shadow'. Such shadows are a core prediction of New Economic Geography models (see Fujita et al., 1999a, 1999b; Krugman, 1993) that also consider the geographical distances at which agglomeration economies occur (e.g., borrowed size concept). Essentially, the concept of an agglomeration shadow refers to *growth shadow effects* that large cities have on their surrounding areas, meaning that the number of firms and amount of urban development (growth) in areas near large cities will be limited because of fierce competition effects (Dobkins and Ioannides, 2001; Partridge et al., 2007, 2008b, 2009a). Moreover, the existence of competition effects caused by *growth shadow effects* could prevent the rise of similarly sized cities in close proximity to one another (Krugman, 1993).

In a sense, as Burger et al. (2015) argue, the concepts of borrowed size and agglomeration shadows therefore can be perceived as two sides of the same coin: certain cities' enjoyment of borrowed size effects entails other cities' suffering from the effects of agglomeration shadows. Indeed, Burger et al. (2015) find that whereas the largest city of an urban region in Northwestern Europe borrows size from smaller cities in that same region to achieve a higher concentration of cultural amenities than expected given its size, the smaller cities within that urban region had fewer amenities because they experienced the agglomeration shadow of the largest city. Therefore, consideration of the existence of agglomeration shadows that multiple centers in a metropolitan area cast over their urban surroundings could shed light upon the agglomeration benefits associated with polycentricity on an intra-urban scale. This consideration could reveal whether centers can be perceived as truly territorial reference points of the metropolitan area because they exert a *growth shadow effect* over their neighboring cities while these neighboring cities simultaneously benefit from a greater proximity to centers—e.g., increased access to a wider type of jobs and amenities. Moreover, this consideration contributes to an exploration of both the dynamic nature of agglomeration economies (see Rosenthal and Strange, 2004) and geographic scope when assessing the polycentric model in a metropolitan area.

Finally, as argued by Camagni and Capello (2015), the macro-territorial scope of agglomeration economies is associated with the paradigm of the urban networks to explain contemporary urban systems (Batten, 1995; Camagni and Salone, 1993; Meijers, 2007c). Essentially, Camagni and Capello (2015) advance the argument that the urban-networks paradigm enables an understanding of how agglomeration provides benefits by exploiting the relationships and flows of cooperation and complementary networks among cities (Camagni and Capello, 2004; Meijers, 2005, 2007b). Therefore, when considering the benefits of agglomeration in a polycentric metropolitan area, this scope of agglomeration economies can be interpreted as follows. Agglomeration benefits also result from the aggregate size of centers through the strength of their integration following the construction of complementary and cooperation networks among the households and firms located in them.

Evidence: polycentricity and performance

As indicated in Table 2.1, the empirical evidence is not conclusive with respect to the extent to which polycentricity is associated with economic, social, and environmental advantages. With respect to economic performance, studies examining the effects of polycentricity on distinct spatial scales (intra-urban, inter-urban and inter-regional) have generally found a positive association. For instance, Meijers and Burger (2010) find that doubling the degree of polycentricity across US metropolitan areas increases their metropolitan labor productivity by an average of 5.1%. Other studies have highlighted similarly positive effects in the areas of employment (García-López and Muñiz, 2013; Partridge et al., 2008a) and population (Partridge et al., 2007, 2008b, 2009a) growth. However, a smaller body of literature has noted either a negative or a statistically insignificant association between polycentricity and population or employment growth (Lee and Gordon, 2007, 2011), labor productivity (Brezzi and Veneri, 2015; Veneri and Burgalassi, 2011) and net new-business formation (Lee and Gordon, 2011).

In terms of social performance, which focuses on polycentricity's social implications (benefits and costs) for individuals or households, no consensus about polycentricity's effects has been achieved. One body of literature shows that spatial configurations that are more polycentric lead to shorter trip distances (Nasri and Zhang, 2014) and travel times (Gordon and Lee, 2014), along with higher income per capita (Meijers, 2013; Partridge et al., 2009b) and a larger number of higher-order urban amenities (Burger et al., 2015). Another body of literature has found a negative or statistically insignificant association not only with those social indicators (Burger et al., 2014a; Goetz et al., 2010; Meijers, 2008a; Schwanen et al., 2004; Veneri, 2010a) but also with other indicators, e.g., the unemployment rate (Meijers and Sandberg, 2008).

Moreover, the effects of polycentricity on environmental performance are unclear. In theory, agglomeration benefits in a polycentric spatial configuration could lead to stronger support for public transit and other, more sustainable modes of transportation such as walking and bicycling, along with lower CO_2 emissions from transportation and less pressure on undeveloped land (see, e.g., Anas et al., 1998; McMillen, 2001a). In this respect, some authors have found that a more polycentric urban system increasingly encourages individuals to use public transportation or other sustainable choices

(Vega and Reynolds-Feighan, 2008), leading to a reduction of transportation-related CO_2 emissions (Veneri, 2010a). However, other studies have highlighted that polycentricity does not play a role in increasing sustainable choices (Schwanen et al., 2004), or diminishing transportation-related CO_2 emissions (Lee and Lee, 2014) or decreasing land consumption (Veneri and Burgalassi, 2012).

The mixed outcomes of research on the relationship between polycentricity and performance can be explained not only by the various approaches to defining and identifying polycentricity on different territorial scales but also by how these approaches have measured the effects of polycentricity. The first approach consists of studies that have examined the effects of polycentricity on an intra-urban scale. In general, these studies identify centers in a metropolitan area; subsequently, they examine the extent to which the agglomeration benefits of centers contribute to better performance. This first approach then examines the agglomeration benefits experienced in a polycentric metropolitan area by considering the geographic scope of agglomeration economies. For instance, the literature on polycentricity on an intra-urban scale and its link to performance has illustrated that the level of agglomeration economies proxied by employment density—and thus, the positive externalities of agglomeration—is attenuated by distance from centers that are identified as being located in a metropolitan area (e.g., García-López and Muñiz, 2010; McMillen and Lester, 2003; McMillen and McDonald, 1998a, 1998b). Similar evidence has also been found with respect to wages in both North American (Glaeser, 2000; White, 1999) and European urban systems (Hohenberg and Lees, 1995); however, there is greater attenuation in European urban systems that is attributable to the longer history of the formation of their central cities, resulting in a higher concentration of amenities (Brueckner et al., 1999).

The second approach consists of studies that have explored the effects of polycentricity on an inter-urban scale. These investigations have frequently explored the advantages of polycentricity by comparing a polycentric constellation to a monocentric one, focusing on the balance between agglomeration benefits and agglomeration costs. This second approach has then analyzed the agglomeration benefits in a polycentric/monocentric spatial configuration by considering the industrial scope of agglomeration economies and in particular, focusing on urbanization (size) externalities. For instance, the literature on the link between polycentricity on an inter-urban scale and performance has advanced the hypothesis that because the advantages of urbanization in polycentric urban structures are 'regionalized' (to a considerable extent), whereas the disadvantages of urbanization remain localized, polycentric urban structures may provide a better balance between the costs and benefits of agglomeration—in marked contrast to monocentric urban structures—and thus, a more positive effect on performance (see, e.g., Burger, 2011; Burger et al., 2014a; Meijers, 2007a, 2008a). However, neither the literature on the link between polycentricity and performance on an intra-urban scale nor the literature that addresses the inter-urban scale has examined the effects of polycentricity on performance by considering all of the different scopes of agglomeration economies (industrial, geographic, and macro-territorial) that are discussed above. Had those studies done so, they could have provided scholars with new insights and broader conclusions related to the extent to which polycentricity contributes to better performance by urban systems.

SPATIAL SCALE UNDER ANALYSIS		ECONOMIC PERFORMANCE: ECONOMIC COMPETITIVENESS			
		Indicator	Positive effect	Negative effect	Not significant
	Intra-urban scale (Davoudi, 2003): monocentric and polycentric model within metropolitan areas	Employment and/or population density	***Studies on the polycentric model function*** (e.g., McMillen and McDonald, 1998a, 1998b; McMillen, 2001b; McMillen and Lester, 2003; García-López and Muñiz, 2010; Sun et al., 2012)		
		Employment growth	***García-Muñiz and Muñiz (2013)***	*Giuliano et al., (2012)*	
		Population density growth	***García-López (2012)***		
		Labor productivity	Cervero (2001)		
	Inter-urban scale (Davoudi, 2003): between regions, metropolitan areas, functional urban areas, or daily urban systems, and within a polycentric urban region	Population growth	Partridge et al. (2007, 2008b, 2009a)		***Lee and Gordon (2007)***, Partridge et al. (2007, 2009a)
		Employment growth	Partridge et al. (2008a)		***Lee and Gordon (2007, 2011)***
		Labor productivity	Meijers and Burger (2010), Veneri and Burgalassi (2012), Meijers (2013)	Veneri and Burgalassi (2011), Fallah et al. (2011) [Role played by sprawl]	Cervero (2001), Veneri and Burgalassi (2011, 2012)
		Net new-business formation			***Lee and Gordon (2011)***
		GDP per capita		Brezzi and Veneri (2015)	Brezzi and Veneri (2015)
		Labor productivity growth			Veneri and Burgalassi (2012)
	Inter-regional scale (Davoudi, 2003)	GDP per capita	Brezzi and Veneri (2015)	Meijers and Sandberg (2008), Vandermotten et al. (2008)	Meijers and Sandberg (2008), Vandermotten et al. (2008)

TABLE 2.1 Empirical evidence on polycentricity and performance in the literature

Note(s): 1) those studies that have identified centers within urban systems using an identification method are represented by bold and cursive letters, whereas those studies that have identified centers by morphologically identifying a set of spatial units in the territory are represented by cursive letters; 2) when a study appears in several columns (e.g., Veneri and Burgalassi, 2012), it illustrates distinct effects of polycentricity depending on how it has measured polycentricity; and 3) this table only represents the empirical evidence of polycentricity, not the link between urban structure and performance, which would have also entailed the consideration of studies that have only defined the degree of monocentricity (e.g., distance to the central city).

Challenges and research gaps

The literature has made progress in exploring the economic, social, and environmental (dis)advantages of polycentricity on an intra-urban, an inter-urban, and an inter-regional scale. However, the lack of conclusive results with respect to the role that polycentricity plays in performance highlighted the challenge of proposing a more comprehensive, systematic empirical framework to attempt to unify the fragmented empirical research on the advantages of polycentricity. It can be argued that research aimed at examining the effects of polycentricity on performance could arrive at broader conclusions about polycentricity's effects by building upon the relationship between polycentricity and theories of agglomeration, thus explaining the development of the agglomeration benefits in a metropolitan area.

	SOCIAL PERFORMANCE: EQUITY, URBAN INEQUALITY, AND SOCIAL WELL-BEING				ENVIRONMENTAL PERFORMANCE: ENVIRONMENTAL SUSTAINABILITY			
	Indicator	Positive effect	Negative effect	Not significant	Indicator	Positive effect	Negative effect	Not significant
	Trip time	*Bell (1991)*, Levinson and Kumar (1994), ***Sultana (2000)***, ***Wang (2000)***, Levinson and Wu (2005), Kim (2008), Anas (2011)	***Cervero (1989b)***, *Cervero and Landis (1992)*, ***Giuliano and Small (1993)***, Wachs et al. (1993), Cervero (1996b), Ewing (1997), ***Cervero and Wu (1998)***, ***Lowe (1998)***, Gutiérrez and García-Palomares (2007), García-Palomares (2010)		Public transport and/or other sustainable mode choice (e.g., walking and bicycling)	Bolotte (1991), ***Vega and Reynolds-Feighan (2008)***, *Naess (2005)*, Aguilera et al. (2009), Anas (2011), *Song et al. (2012)*	Cervero (1989a), *Bell (1991)*, *Cervero and Landis (1992)*, *Pivo (1993)*, Naess and Sandberg (1996), ***Cervero and Wu (1997, 1998)***	*Naess (2010)*
	Trip distance	Wachs et al. (1993), ***Cervero and Wu (1997)***, ***Wang (2000)***, *Naess (2005)*, Gutiérrez and García-Palomares (2007), Kim (2008), Aguilera et al. (2009)	*Cervero and Landis (1992)*, Naess and Sandberg (1996), ***Cervero and Wu (1998)***, ***Aguilera and Mignot (2004)***, ***Aguilera (2005)***, *Naess (2006)*, García-Palomares (2010)	*Naess (2006)*, ***Shearmur (2006)***				
	Trip time	Gordon and Wong (1985), Gordon et al. (1988, 1989a, 1989b, 1991), ***Lee (2006b)***, ***Yang et al. (2012)***, ***Gordon and Lee (2014)***	***Cervero (1989b)*** Schwanen and Dijst (2002), Schwanen et al. (2002, 2003, 2004), Susilo and Maat (2007)	Levinson and Kumar (1997), Schwanen et al. (2002, 2003, 2004), ***Lee (2006b)***, ***Veneri (2010a)***	Public transport and/or other sustainable mode choices		Schwanen et al. (2001, 2002), Dieleman et al. (2002)	Schwanen et al. (2004)
					Mobility impact index (travel mode and trip time)	Travisi and Camagni (2005), Travisi et al. (2006, 2010)		
	Trip distance	Schwanen et al. (2001), Crane and Chatman (2003), ***Nasri and Zhang (2014)***	Schwanen et al. (2001, 2004), Dieleman et al. (2002), Melo et al. (2012), ***Lee and Lee (2014)***	Levinson and Kumar (1997), Schwanen et al. (2001, 2004)	CO_2 emissions from transportation	***Veneri (2010a)***	***Lee and Lee (2014)***	
					CO_2 emissions from households	***Lee and Lee (2014)***		
	Income per capita, mean annual wage, or income spatial distribution	Partridge et al. (2009b), Goetz et al., (2010), Meijers (2013)	Veneri and Burgalassi (2012)	Goetz et al. (2010), Veneri and Burgalassi (2012)	Energy from transportation	Veneri and Burgalassi (2012)		Veneri and Burgalassi (2012)
	Cultural or retail amenities	Burger et al. (2015)	Meijers (2008a), Burger et al. (2014a)	Burger et al. (2014a)	Land consumption		Veneri and Burgalassi (2012)	Veneri and Burgalassi (2012)
	Distribution of GDP per capita			Vandermotten et al. (2008)				
	Unemployment rate		Meijers and Sandberg (2008)	Meijers and Sandberg (2008)				

Based on the literature on polycentricity and theories of agglomeration, it seems that the effects of polycentricity on an intra-urban scale on performance should be measured by considering, as shown in Figure 2.2, three distinct dimensions of a polycentric spatial configuration that play a role in the development of agglomeration economies in a metropolitan area. The first dimension considers the agglomeration benefits that arise out of centers' size (Figure 2.2a). This first dimension illustrates that households and firms located in centers enjoy greater advantages (e.g., greater accessibility to amenities (for people) and opportunities (for firms) for more innovative processes) compared to households and firms located outside of centers because the larger size of a center increases the level of its agglomeration economies. The second dimension considers the distance-related attenuation of the agglomeration benefits that arise out of centers' size (Figure 2.2b). This second dimension stresses that centers' agglomeration economies are not confined to city boundaries:

indeed, they cross boundaries to reach the surrounding areas. That means that households and firms located near centers benefit more than those located further from centers because the former group enjoys greater proximity to centers' agglomeration economies. The third dimension considers the agglomeration benefits that result from the aggregate size of centers through the strength of their integration (Figure 2.2c). The key element of the development of agglomeration economies through this third dimension is the presence of strong complementary or cooperation networks among households and firms located in centers because these networks foster interaction and integration among centers that in turn empower them to better exploit their aggregate urban size. When centers exploit their aggregate urban size according to the strength of their integration, households and firms located in (or near) these centers—that are spatially integrated into the metropolitan urban system—experience additional advantages compared to those experienced by households and firms located in less-integrated locations of the metropolitan area (e.g., households located in one of these 'spatially integrated' centers not only enjoy a greater accessibility to several types of jobs and amenities resulting from the urbanization advantages of the center in which they are located but also enjoy a greater accessibility to the agglomeration benefits of the other 'integrated' centers).

As explained in section 2.1, the absence of a clear conceptualization of polycentricity is also a reason for the unsolved empirical discussion of polycentricity and performance. Whereas polycentricity on an intra-urban scale focuses on the appearance and identification of centers in metropolitan areas, polycentricity on an inter-urban scale focuses much more closely on the analytical definition of a polycentric urban region. The literature on the definition of polycentricity on an intra-urban scale has not achieved consensus about how to identify centers. Although a US-based literature has addressed the spread of employment to fit the decentralization trajectory toward polycentricity, a Europe-based literature has examined the functional relationships between urban areas to satisfy the incorporation-fusion pathway to polycentricity. That said, the literature discussed above sheds more light on this lack of consensus about the conceptualization of polycentricity on distinct spatial scales. It perceives the relationship between polycentricity and performance in a manner that is based on the role played by agglomeration economies that have developed in the set of centers that define a polycentric spatial structure. This point is of the utmost importance and relates to the question of why it is important to identify centers in the first place. Differences in the centers identified in an urban system lead to distinct polycentric spatial configurations within a single metropolitan area. Thus, the agglomeration benefits of centers, which are the key to assessing the influence of polycentricity on metropolitan performance, also vary according to the method used to identify centers. Therefore, it can be argued that discrepancies in the literature with respect to the effects of polycentricity on performance result from the dependency link between agglomeration benefits and the 'distinct' polycentric structures identified in a metropolitan area. Therefore, a second key point for defining a more comprehensive and systematic empirical framework to analyze the link between polycentricity and performance is the need to comprehensively identify all of the urban areas in a metropolitan area that has a greater spatial concentration of agglomeration economies, as shown in Figure 2.3.

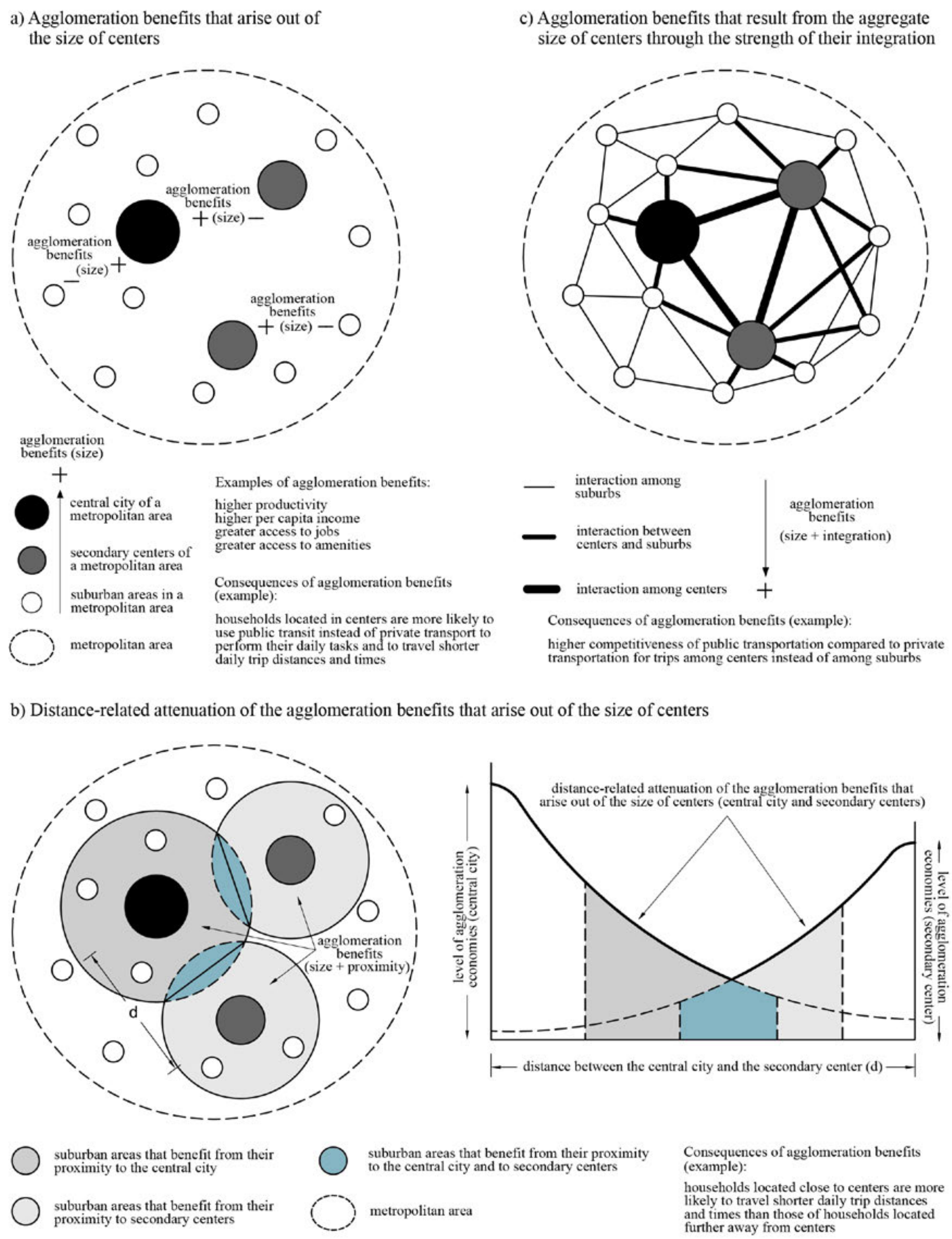


FIGURE 2.2 Conceptual approach to the relationship between polycentricity and the performance of a metropolitan area based on theories of agglomeration.

The challenge of creating a method to identify centers in metropolitan areas that integrates both of the origins of polycentricity (i.e., the decentralization and incorporation-fusion trajectories presented in section 2.1) could therefore contribute to a more accurate description of the polycentric urban context for use in studying the advantages of polycentricity. Indeed, it can be argued that because the origin of centers is a matter of significance for the presence of various types of agglomeration economies, thus influencing centers' agglomeration benefits, the identification of both types of centers (i.e., those resulting from decentralization versus incorporation-fusion) is essential to understand the spread of agglomeration economies in metropolitan areas. For example, as Figure 2.3 suggests, centers arising out of incorporation-fusion seem to have greater urbanization (advantages) economies than centers originating from decentralization because of the generally larger city size and more diversified economic structure associated with the former type of center. This means that centers arising out of incorporation-fusion could develop greater agglomeration benefits. Moreover, the distinct trajectories toward forming centers are significant to agglomeration economies, which are derived from the size and proximity of centers (see Figure 2.3). The agglomeration economies of centers that arise out of incorporation-fusion could experience greater distance-decay effects than do the agglomeration economies of centers that arise out of decentralization. This means that households located near centers that arise out of incorporation-fusion (e.g., within a radius of 5 kilometers) not only will benefit more from this proximity but also will be more dependent on their access to the agglomeration benefits stemming from these centers than are households located close to centers that arise out of decentralization. Similarly, a center's origin also influences the development of agglomeration economies in a polycentric structure that arise out of the size and level of integration among centers. As Champion (2001:664-665) notes, centers that arise out of the decentralization of economic activities and urban functions from the central city, unlike centers that arise out of incorporation-fusion, tend to establish competitive—not complementary—relationships among themselves. In other words, greater agglomeration economies could be developed by centers that arise out of incorporation-fusion because of those centers' higher integration, which results from their potential to build complementary networks (see Figure 2.3).

In light of the literature on polycentricity and performance, two interrelated final challenges or research gaps related to the conceptualization of polycentricity on an intra-urban scale can be added. First, the polycentric New Urban Economics models that emphasize the attenuation of agglomeration economies as distance from centers increases (e.g., McMillen and McDonald, 1998a, 1998b; McDonald and Prather, 1994) and the New Economic Geography models that stress the presence of agglomeration shadows from centers could be integrated, thus contributing to a comprehensive assessment of the polycentric model and a further discussion of polycentricity and metropolitan performance. For instance, as discussed above, the study of *growth shadow effects* contributes to an exploration of both the dynamic nature (temporal scope) of agglomeration economies (see Rosenthal and Strange, 2004) and the geographic scope when assessing the polycentric model in a metropolitan area.

Second, I propose creating a new, theory-informed conceptualization of what a center is by building upon this better integration between the New Urban Economics and the New Economic Geography literature: centers are not only places with the highest level of agglomeration economies in a metropolitan area but also places that cast the most wide-ranging (spatially), powerful agglomeration shadows over their surroundings. Therefore, the center's concept would not be exclusively static; instead, it would be placed into a dynamic perspective: a center in a metropolitan area must cast an 'agglomeration shadow' (*growth shadow effects*) over its surrounding areas, meaning that the number of firms and amount of urban development (growth) in areas near a center will be limited because of fierce competition effects

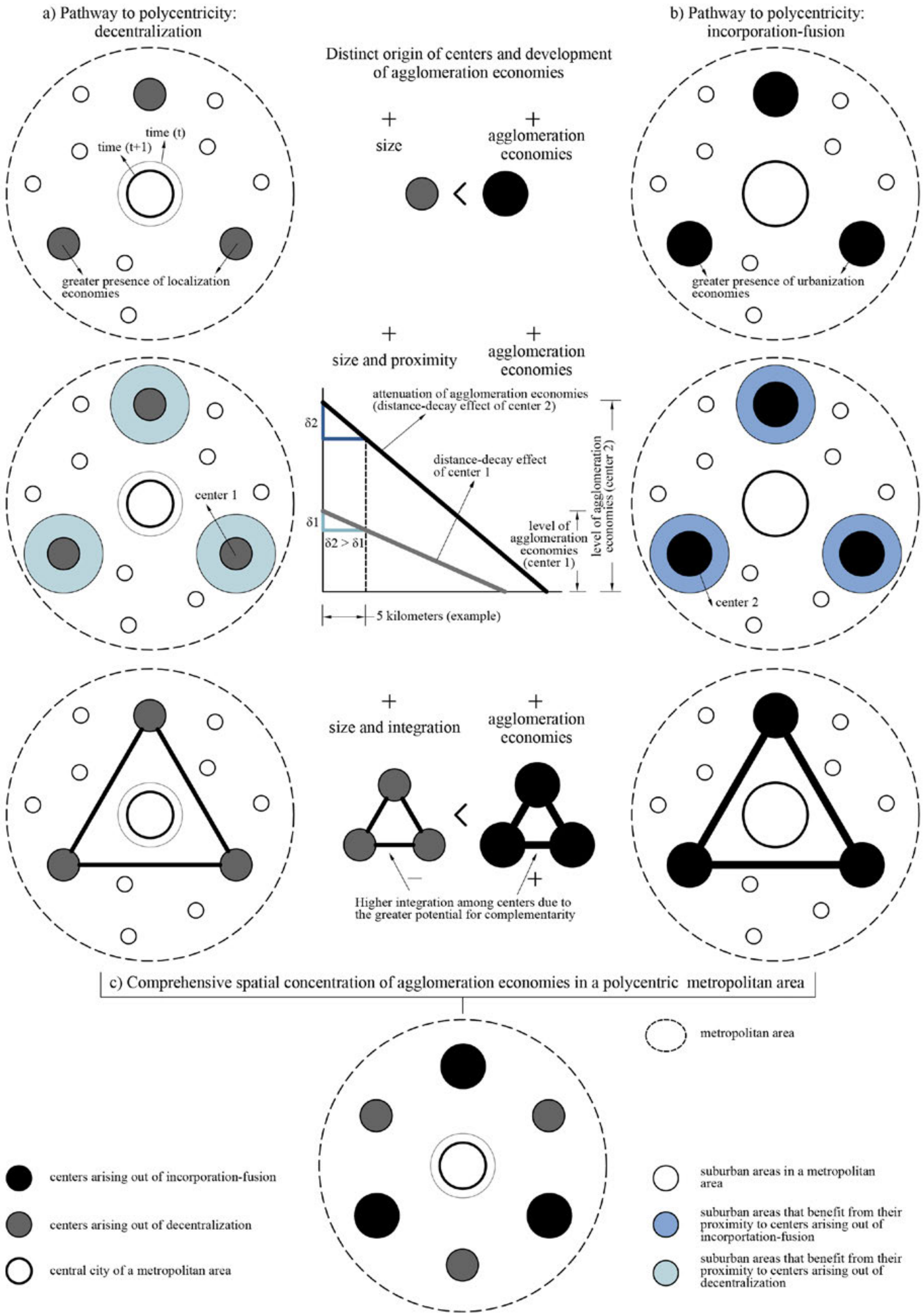


FIGURE 2.3 Distinct trajectories to the formation of centers in a polycentric metropolitan area and theories of agglomeration

§ 2.4 Polycentricity and planning

The final stream in the polycentricity literature concerns planning practice related to this urban form. Attention to the interplay between spatial plans and urban form is rooted in the early 1990s, when—after two decades of focusing on local urban development projects and land-use regulations—planners renewed their interest in producing strategic frameworks and visions (imaginations) for the territorial development in cities and regions, strongly emphasizing their relationship with *sustainable development* (Albrechts et al., 2003; Oliveira and Pinho, 2010). Several planning concepts then emerged in the literature to create a bridge between *sustainable development* (broadly interpreted as fulfilling economic, social, and environmental objectives) and territorial development. Those concepts include 'Smart Growth', 'New Urbanism', and 'Transit-Oriented Development', particularly in North America, whereas 'Compact City' and 'Polycentricity Development' were largely developed in Europe.

Today, the concept of polycentric development appears as the main hallmark of worldwide spatial plans (see chapter 1, section 1.1). The adoption of polycentricity in the 1999 European Spatial Development Perspective as a key normative goal to promote economic competitiveness, social cohesion, and environmental sustainability across the European territory on distinct spatial scales might have reinforced its potential to appear to be a more suitable spatial strategy than other planning concepts for achieving *sustainable development* in European spatial plans. Although the application of polycentric development in spatial plans for metropolitan regions therefore created important expectations among scholars and policymakers, it also raised major issues within planning practice.

Expectations and issues

The primary expectation grounding polycentric development in metropolitan areas, as set forth in the 1999 European Spatial Development Perspective, is that a polycentric urban system that is as balanced as possible spurs a more even spatial distribution of population, economic activities, and urban functions, along with higher levels of functional integration and complementarity among centers. In turn, spatial outcomes could discourage excessive agglomeration diseconomies of large centers while also enabling the achievement of sufficient a critical mass for enjoying the agglomeration benefits of a single large center (Davoudi, 2003; Faludi, 2004b).

These expectations of polycentric development can also be found in later European policy documents. The European Ministries that share responsibility for urban development with the European Commission have developed a Territorial Agenda, which states that "*we would like to promote a polycentric development… with a view making better use of available resources in European regions… In this way we will contribute to a Europe which is culturally, socially, environmentally and economically sustainable*" (EC, 2007a:1). The 2007 Leipzig Charter on Sustainable European Cities also highlighted a firm commitment to promote polycentric development as a basis for creating a territorial organization based on the pillars of economic prosperity, social balance, and health environment (see EC, 2007b). Similar claims have been made in the independent report 'An Agenda for a Reformed Cohesion Policy', better known as the 'Barca Report' (Barca, 2009), which emphasizes the role of networked polycentric regions (in contrast to their monocentric counterparts) as a driver of growth and balanced development. More recently, the Territorial Agenda of the European Union 2020 (EC, 2011a) and its update (EC, 2011b) have strongly emphasized inclusive, smart, and sustainable growth. However, those reports continue to perceive polycentric development as a key development strategy: "*Polycentric development can be a key element for achieving territorial cohesion, where the most developed cities and regions are distributed in a balanced way… in this way added value can be* *achieved and the strong centers can contribute to the development of their wider regions… cities are encouraged to form networks… to improve their performance*" (EC, 2011b:80).

In this light, it is unsurprising that planners and policymakers in distinct European countries are generally convinced that polycentric development yields benefits in terms of an efficient public transportation system and greater accessibility to amenities and local services, thus potentially rendering metropolitan areas more economically competitive because of the greater potential to exploit cities' polycentricity-related critical mass, diversified economic structure, and division of labor (see Schmitt, 2013). However, the promotion of polycentric development in spatial plans for metropolitan regions has raised significant issues among both planners and policymakers about the implementation of spatial plans, particularly with regard to the extent to which a plan's intentions depart from its spatial outcomes, a situation referred to in the planning literature as a plan's 'degree of conformance'.

Two primary issues can be distinguished. The first issue relates to the concept of polycentricity and how it affects metropolitan performance. The second issue relates to the governance implications of the application of a polycentric development strategy in metropolitan areas. With respect to the first issue, the essential problem is that implementation of a polycentric development policy 'on the ground' creates many uncertainties because of the lack of conceptual clarity and the presence of contradictory empirical evidence around polycentricity in the literature. This uncertainty can be somewhat problematic for planning policies because it could mean that the outcomes of a plan, including its unintended effects, significantly depart from the plan's objectives, thus potentially causing the plan's failure, as measured by a conformance-based evaluation (see Baer, 1997; Laurian et al., 2004, 2010; Loh, 2011 for a detailed explanation on conformance of spatial plans).

With regard to the second issue, problems may arise from either the mode of governance or the lack of political support to match the polycentric metropolitan region's perceived boundaries to the existing legal-administrative borders. Both problems are of great importance to avoid non-conformance of the plan because the absence of 'governance capacity' (e.g., a powerful metropolitan government) or political commitment to establish effective policy-making on a proper scale could hamper the achievement of the positive agglomeration externalities associated with polycentric development, and thus some of the plan's planning goals. Moreover, other governance problems may also arise, even when there is effective organizational capacity for policymaking (e.g., metropolitan government) and when political actors make a long-term commitment to implement polycentric development. These issues relate to the administrative organization (and fragmentation) of the territory because institutional actors may inhibit the development of a strategic planning capacity: for instance, there may be vertical power struggles between various tiers of government (e.g., more centralization or devolution between regional and national governments) and horizontal competition among local governments (e.g., allergies towards complementarity and a propensity to duplicate functions).

Challenges and research gaps

Polycentric development has become a key territorial development strategy in planning practice to achieve the economic, social, and environmental objectives of spatial plans. However, the academic literature's lack of clarity around the concept of polycentricity, the contradictory evidence about how polycentricity affects performance (see sections 2.2 and 2.3) and the issues relating to its governance implications pose major challenges or research gaps related to improving the effectiveness and feasibility of polycentric development in spatial plans. From this dissertation's perspective, these challenges indicate how to better conceptualize polycentric development in spatial plans and how the assumed benefits of polycentricity can be realized in planning practice. In addition, most of these challenges underline the need for a more evidence-informed planning (see Davoudi, 2006; Faludi and Waterhout, 2006) that, compared to evidence-based planning, recognizes that evidence is not the only factor that influences policy: factors such as ideology, interests, the influence of institutional tradition and prior information also play important roles (see Weiss, 2001). In practice, this stress on an evidence-informed planning could mean that polycentricity will become a bridge-building tool between research (evidence) and policy (plans). Thus, it can be argued that the use of an improved understanding of polycentricity in planning resulting from paying closer attention to the ongoing polycentricity debate in research could contribute to address the polycentric-development issues discussed in the previous subsection.

For this reason, three challenges can be posed to hypothesize how polycentric development could be better conceptualized in spatial plans for metropolitan areas and how the assumed advantages of polycentricity can be realized in planning practice. The first challenge is to empirically identify centers in metropolitan areas. The second challenge is to measure the degree of polycentricity in metropolitan areas. The third challenge is to empirically estimate the effects of polycentricity on metropolitan performance to bring these effects, in an evidence-informed form, to architects, planners, and policymakers alike.

The empirical identification of centers could provide spatial plans with good insight into the spread of agglomeration economies over a metropolitan area. Because polycentricity's potential advantages depend on the agglomeration benefits that arise out of centers (see section 2.3), the achievement of a spatial plan's economic, social, and environmental objectives could suffer from the use of a non-empirical method to identify a metropolitan area's polycentric structure for planning purposes. Consequently, the evaluation of various identification methods of centers against their fit with the theoretical and empirical polycentric models adopted in the economics literature, which enable an understanding of the costs and benefits of a polycentric structure (see section 2.3), would shed light on the extent to which knowledge of the academic literature on polycentricity could contribute to a better understanding of polycentric development in planning.

Measuring the degree of polycentricity in a manner that considers both its morphological and functional dimensions could provide spatial plans with complementary arguments about the extent to which polycentric development is preferred over alternative territorial models. Because a polycentric configuration cannot exist without a minimum spatial balance in the distribution of urban attributes, a minimum level of spatial integration, and complementarity among a metropolitan area's centers, measuring polycentricity could shed more light on the extent to which supporting a polycentric development strategy is convenient if the metropolitan area is not already polycentric. Additionally, measuring the degree of polycentricity could contribute to clarifying not only the understanding of a polycentric development strategy and its expectations but also how to monitor the implementation of a polycentric development strategy. For example, the absence of strong spatial integration and complementary relationships among centers may reveal that it is unrealistic to expect to be able to link an efficient public transportation system to the various centers of a metropolitan area.

An empirical analysis of the relationship between polycentricity and performance could offer spatial plans with new perspectives on the extent to which their economic, social, and environmental objectives could be fulfilled. In particular, using the estimated effects of the link between polycentricity and performance (if there is a statistically significant association between them) to elaborate evidence-informed policies can contribute to setting attainable performance targets, which in turn could also easily meet the plan's objectives. For instance, if polycentricity reduces daily trip distances and times for households located in centers and their neighboring areas by 15% and 5%, respectively, compared to households located elsewhere in the metropolitan area, this evidence-informed knowledge could be used, if the makers of the plan are in agreement after considering other factors that influence policy, both to allocate urban developments foreseen for the metropolitan area and to simulate the extent to which polycentricity will reduce individuals' trip distance and time by the horizon year of the spatial plan.

Addressing these challenges could also provide spatial plans with useful insights into the polycentric development-related governance issues discussed above. A better policy understanding of polycentricity could be useful to build organizational capacity among various governments on various scales, to target stakeholders with the goal of obtaining their commitment to the plan's territorial model and to support the establishment of a powerful metropolitan government on an appropriate scale. For example, if the measurement of spatial integration among centers in multiple urban networks shows that these centers operate as a functional, integrated entity, this finding could shed more light on the perceived boundaries of the metropolitan area (and therefore, the area's most appropriate boundaries) to form a powerful metropolitan government with an effective policy that guarantees achievement of the positive agglomeration externalities associated with polycentricity.

§ 2.5 Research approach

The debate on polycentric urban systems has made increasing progress in terms of the conceptualization, empirical evidence, and policy implications of polycentricity. However, as the previous three sections (2.2-2.4) have highlighted, there are numerous interwoven challenges and research gaps. It is necessary to address these challenges and research gaps to achieve this dissertation's threefold aim and its three general research questions, all of which are presented in the introduction (see chapter 1).

That said, it is not possible to close all of the research gaps identified in the previous sections within the framework of a single thesis. Therefore, choices must be made. For that reason, this dissertation does not focus on all of the dimensions of the relationship between polycentricity and performance, instead focusing on their link through the lens of travel behavior of individuals. This analytical perspective could enable a novel exploration of the extent to which agglomeration benefits in a polycentric metropolitan area influence individuals' travel behavior (e.g., trip distance and choice of travel mode), following the conceptual approach to the link between polycentricity and performance proposed by this dissertation (see Figure 2.2). As discussed above, considering the distinct dimensions of a polycentric spatial configuration that play a role in the development of agglomeration benefits—namely, the size of centers, (geographic) proximity to centers, and the aggregate size of centers through their integration—contributes to building a more comprehensive, systematic empirical framework to attempt to unify the fragmented empirical research on polycentricity's advantages, thus arriving at broader conclusions about polycentricity's effects. Furthermore, because one chapter of this thesis aims to identify centers and their formation from the tension between agglomeration economies and agglomeration diseconomies (see Anas et al., 1998), the relationship between polycentricity and economic performance is also addressed through an empirical assessment of the polycentric model: the attenuation of the level of agglomeration economies (proxied by employment density) with the distance from centers could indicate that agglomeration positive externalities (e.g., labor productivity, see Ciccone and Hall, 1996) also decrease with decreasing proximity to centers.

The remainder of this section presents the specific research questions that address this thesis's general research questions, following not only the challenges and research gaps highlighted in the previous three sections but also the criterion discussed above. Additionally, a brief description of the research methods and data used in this dissertation to answer the research questions is provided. It is important to mention that these specific research questions focus on the single case study of the Barcelona metropolitan region; accordingly, their answers cannot be directly generalized to other metropolitan regions. However, because the Barcelona metropolitan region has key characteristics that allow it to be perceived as a representative case study among an appropriate population of worldwide metropolitan regions (as discussed in the introduction to this thesis (see section 1.3)), answers to the following specific research questions could provide relevant learning potential for other metropolitan regions.

Specific research questions

The first general question (chapters 3 and 4) is as follows: How has the conceptualization of polycentric development in spatial plans evolved over time, and what can be learned from this evolution? The specific research questions related to this general question are as follows:

1 To what extent does Catalonia/Barcelona have a tradition of promoting polycentric development in planning? Which factors have influenced the emergence of such a tradition, and how has this polycentric vision evolved over time?
2 To what extent is the polycentric model preferred over alternative territorial models of development models in the most recent spatial plan for the Barcelona metropolitan region? To what extent does a polycentric development vision correspond to actual development?

The second general question (chapters 5 and 6) is as follows: How has polycentricity been conceptualized in research, and how can it inform planning practice? The specific research questions related to this general question are as follows:

3 To what extent is an empirical method of identifying centers more accurate than the approach used by the 2010 Barcelona Metropolitan Territorial Plan in defining the polycentric model in the Barcelona metropolitan region?
4 To what extent can the metropolitan structure of Barcelona be considered polycentric from a morphological and functional perspective, and how can that structure inform planning practice?

The third general question (chapters 7 and 8) is as follows: To what extent does polycentricity foster better performance in a metropolitan area, and how can its effects be realized in planning practice? The specific research questions related to this general question are as follows:

5 To what extent do people living in a center conduct their daily activities in that or another center? To what extent do people who do not live in a center conduct their daily activities in the center that is closest to them?
6 To what extent does polycentricity encourage sustainable travel mode choices, and how can its effects be realized in planning practice?
7 To what extent does polycentricity reduce trip distance, travel time and transportation-related CO_2 emissions, and how can its effects be realized in planning practice?

Methods

Several methods will be used both to address these general (and specific) research questions and to explore how the multiple relationships among polycentricity, performance, and planning manifest themselves in the Barcelona metropolitan region. The methods used include qualitative methods such as policy/discourse analysis to answer the first general research question about how the conceptualization of polycentric development in spatial plans has evolved over time and what can be learned from this evolution. Additionally, this thesis employs quantitative methods such as descriptive statistics, correspondence analysis, simple regression models, and advanced regression models (in which both spatial autocorrelation and endogeneity issues are controlled to avoid biased estimation results) to address the second general question, which refers to how polycentricity has been identified and measured in research and how this identification and measurement of polycentricity can inform planning practice. Finally, this research uses advanced statistical methods to answer the third general question of the extent to which polycentricity fosters better performance in a metropolitan area and how the effects of polycentricity can be realized in planning practice. I use both multilevel multinomial logit models and multilevel structural equation models. Because of the use of these models, this dissertation can explain the estimated effects (e.g., average marginal effects and total, direct, indirect elasticities) of the link between polycentricity and performance to architects, planners, and policymakers in an evidence-informed form.

Several of these models have never been applied to the field of polycentricity, performance and planning; therefore, they can provide novel answers to the research questions. For instance, the implementation of multilevel modeling in the estimation of multinomial logit models could represent the first application of multilevel multinomial logit models in the literature on the relationship between polycentricity and travel mode choice. Another good example is the application of multilevel structural equation models to explore the link between polycentricity and travel behavior externalities, which will allow this dissertation to take the novel step of addressing both the composite (direct and indirect) effects of polycentricity and the potentially biased estimation problems that arise from the use of hierarchical data. More details about these methods and their application and contribution are provided in the corresponding chapters.

Data

Multiple datasets have also been employed to answer this thesis's research questions. They include a wide range of data provided by several sources, including the following: the IDESCAT (*Institut d'Estadística de Catalunya*: Statistic Institute of Catalonia) supplied the census data; the ATM (*Autoritat del Transport Metropolità:* Metropolitan Transportation Authority) provided the EMQ (*Enquesta de Mobilitat Quotidiana*: Daily Mobility Survey); and the Catalan government's DPTOP (*Departament de Política Territorial i Obres Públiques*: Department of Territorial Policy and Public Works), today known as the Department of Territory and Sustainability, provided data on, for example, the minimum road distances (in kilometers) between Catalonia's municipalities.

The use of these datasets has allowed this thesis to make several contributions to the literature. First, it increases the knowledge of the impact of polycentricity on travel mode choice and travel behavior externalities related to the purposes of various non-work-related trips. Second, it augments the numerous studies that have aimed to analyze the extent of the overlaps that appear in the measurement of polycentricity among distinct urban networks such as shopping, leisure, and business flows ('multiplexity'); various individuals' attributes within each type of network, such as age, sex and educational level ('individual-level heterogeneity'); and conceptions of the regional economy (sectoral and occupational). Third, this thesis conducts a novel examination of the role played by infrastructure improvements, which may also influence the rise of new centers over time, in the assessment of the polycentric model.

It was not always possible to use the desired (and foreseen) data. This was the case, for example, with the 2011 census data, which do not provide an exhaustive analysis of population and housing (as in the 1991, 1996, and 2001 censuses) because of government cutbacks following the economic crisis. Details about these datasets and how (in some cases) this dissertation has attempted to address their limitations are explained in the appropriate chapters.

PART 2 Polycentricity and Planning

3 The planning debate in Catalonia 1901-2010: between monocentrism and polycentrism

§ 3.1 Introduction

Since the early 20th century, Barcelona and Catalonia's territorial organization has been extensively discussed by architects, geographers, intellectuals, and politicians. In the debate, two opposing models of the territorial organization take center stage (Cassasas, 1977; Lluch and Nel·lo, 1984; Nadal, 1991; Pujol, 1997; Roca, 1976, 1977; Tarragó, 1972). On the one hand, we have the polycentric territorial model. This model responded to the negative aspects of large industrial cities, which were a key issue of concern in several social, cultural (intellectual) and political movements in Catalonia in the early 20th century. These concerns led to the 1932 *Regional Planning* proposal by Nicolau M. Rubió-Tudurí and the 1936 *Divisió Territorial de Catalunya* conceived by Pau Vila. On the other hand, we have an opposing territorial model, which proposed a monocentric vision of Catalonia that aimed to reinforce Barcelona as an important international capital. This vision resulted in the 1934 *Pla Macià* or *Nova Barcelona* designed by Le Corbusier and GATCPAC (*Grup d'Arquitectes i Tècnics Catalans per al Progrés de l'Arquitectura Contemporània*). The latter represented the architecture movement, which advocated the CIAM's (International Congresses of Modern Architecture) ideas in Catalonia. From the 1930s, a few years before the Spanish Civil War, until after the restoration of democracy in 1976, these opposing planning visions were central to the debate, inspiring various other spatial plans.

The aim of this chapter is to study the spatial development proposals for Barcelona and Catalonia and the territorial model advocated by those spatial proposals. This study will reveal a transformation in the conceptualization of polycentric development in successive spatial plans. The analysis is embedded, as shown in Table 3.1, into both a more general discussion of the historical context and the international debates that influenced the spatial plans that we consider here. This chapter answers the specific research question (see section 2.5 in chapter 2) about the extent to which Catalonia/Barcelona has a tradition of promoting polycentric development in planning and which factors influenced the emergence of such a tradition. Additionally, the evolution of ideas about polycentricity over time will be addressed. To adequately cover this research question, it is necessary to consider a relevant and extended period of analysis. The period analyzed in this study ranges from 1901 to 2010, which enables a study of early 20th-century social, cultural and intellectual movements that had a profound impact on Catalonia's first planning proposals. Additionally, the study of this period permits an examination of planning proposals during the Spanish dictatorship, along with spatial plans since the restoration of democracy through approval of the *Generalitat de Catalunya*'s (Government of Catalonia) most recent territorial plan for the Barcelona metropolitan region. This last plan, however, will be thoroughly discussed in the next chapter.

Answering the aforementioned specific research question also teaches interesting lessons about how an understanding of polycentric development in planning addresses the ongoing academic debate on polycentricity and its link to the performance of metropolitan areas (see Figure 1.3 in the introduction). For instance, this understanding provides valuable insights into the definition of the polycentric territorial model in spatial plans and how planners assume that this territorial development strategy fulfills their economic, social and environmental objectives.

The organization of the remainder of this chapter follows three distinct periods in recent Spanish history: before, during, and after the Spanish dictatorship (see Table 3.1). The main reason for this organizational choice is that because these periods defined clearly divergent historical contexts, the influence of the historical context and its social, cultural, and political consequences on the distinct spatial plans could be better disentangled. Section 3.2 analyzes the period that set the scene for the planning debate in Catalonia (1901-1939). Section 3.3 is devoted to the evolution of the planning debate during the dictatorship (1939-1976). Section 3.4 examines how the polycentric model has come to dominate the discussion about the territorial organization since the restoration of democracy until the present (1976-now). Finally, section 3.5 concludes by synthesizing the understanding and evolution of the planning vision of polycentricity in Catalonia/Barcelona and discusses how these distinct definitions of polycentric development in planning could be more closely linked to the academic debate on polycentricity.

HISTORICAL PERIODS (1901-2010)			SPATIAL PLANS: NAME	SPATIAL PLANS: CHARACTERISTICS			
				Approved (status of the plan)	Delimitation	Main makers of the plan	
HISTORICAL PERIODS (1901-2010)	The roots of the debate about polycentricity (1901-1939)		The 1932 Regional Planning	Not approved (no statute)	The entire Catalan territory	Nicolau M. Rubió-Tudurí (architect)	
			The 1934 Pla Macià or Nova Barcelona	Not approved (no statute)	The capital city of Barcelona and its surrounding urban areas	GATCPAC and Le Corbusier (architects)	
			The 1936 Divisió Territorial de Catalunya	Approved (Decree of 23 December 1936)	The entire Catalan territory	Pau Vila (geographer)	
	Visions of polycentricity during the dictatorship (1939-1976)	continuity (1939-1959)	The 1953 Pla Comarcal de Barcelona (PCB)	Approved (Decree of 3XII - 1953)	The region (*comarca*) of Barcelona formed by 27 municipalities	José Soteras Mauri (architect)	
			The 1959 Pla Provincial de Barcelona	Not approved (revision of the PCB)	The province (*província*) of Barcelona formed by 11 regions (*comarques*)	Pedro Bidagor and Manuel Baldrich (architects)	
		change (1956-1979)	The 1966 Pla Director de l'Àrea Metropolitana de Barcelona	Not approved (working documents approved)	A territory between the region and province of Barcelona (7 regions and 160 municipalities)	José María Ros Vila (architect)	
			The 1976 Pla General Metropolità de Barcelona	Approved (Decree RD 1346/1976)	The region (*comarca*) of Barcelona formed by 27 municipalities	Joan Antoni Solans (architect) and Albert Serratosa (engineer)	
	The polycentric vision and the territorial model after the restoration of democracy (1976-2010)		The 1995 Pla Territorial General de Catalunya (PTGC)	Approved (Decree 1/1995)	The entire Catalan territory	Genís Carbó (architect)	
			The 1998 Pla Territorial Metropolità de Barcelona	Provisional proposal	A territory formed by 164 municipalities and 7 regions according to PTGC	Albert Serratosa (engineer)	

TABLE 3.1 Planning visions for Barcelona and Catalonia: 1901-2010

Main planning concepts	Methodology of the plan to achieve its objectives	Polycentric vision of the plan (main international reference)
Decentralization of population and economic activities. Development of urban centers with limited size.	Prescriptive: the *urbanization of the country* by distinguishing 12 distribution zones.	Polycentricity as a decentralization strategy (Garden cities theory and American City Planning).
Barcelona as a functional city (capitalism model) but aiming to mitigate the social problems stemming from industrialization.	Prescriptive: urban extension characterized by grid pattern, vacation city, zoning, and urban renewal of the historical city center.	Monocentric conception. Configuration of the business zone following Le Corbusier (1924) and limited territorial scale.
Defining an alternative administrative division (regions) for the entire Catalan territory that represents its market relationships.	Quantitative: a query to identify and delimit the main city-markets (*ciutat-mercats*) of Catalonia.	Polycentric model based on hierarchical relationships. Definition of 38 central places with their own hinterlands ('Central Place Theory').
Balanced territory. Limiting urban growth. Avoiding the absorption of more municipalities by the capital city of Barcelona.	Prescriptive: applying a zoning proposal based on 39 distinctive zones Quantitative: fixing the future city size by 2000.	Polycentricity as a decentralization strategy (Abercrombie, 1945; Mumford, 1938; Saarinen, 1947).
Balanced development. Improvement of habitat conditions. Protecting the natural landscape.	Prescriptive: applying a zoning proposal and promoting a set of city-regions. Quantitative: Prospective study of population until 2000 to constrain inter-city migration.	Polycentricity as a decentralization strategy based on the idea of city-region (*ciutat-comarca*) coined by Baldrich (1952).
Social and economic homogeneity. Plan as an operative hypothesis for 45 years. Accepting urban growth.	Prescriptive: creation / reinforcement of centers, and infrastructures (axial model). Quantitative: prospective study of population through 2010.	Polycentricity as a decentralization strategy and as a manner to organize and canalize urban development (De Carlo, 1962: *città-regione*).
Achievement of a more balanced territory and a more homogenous distribution of urban centers.	Prescriptive: applying city's dynamics zoning and promoting alternative service centers to Barcelona (named *Centres Direccionals*)	Polycentricity as a decentralization strategy.
Boosting economic development. Balancing territory. Organizing urban growth to favor quality of life.	Prescriptive: planning guidelines for subsequent territorial partial plans. Quantitative: prospective model of population until 2026.	Polycentric network of cities. Non-hierarchical and complementary, along with hierarchical relationships, organize the Catalan territory (Dematteis, 1985, 1990, 1991).
In accordance with the *Pla Territorial General de Catalunya* approved in 1995.	Quantitative: 4,700,000 inhabitants for the Barcelona metropolitan region by 2026, in accordance with the PTGC.	Polycentricity as a city of cities. Formulation of this polycentric network as *metropolitan city blocks and regions* (see Generalitat de Catalunya, 1998).

§ 3.2 The roots of the debate about polycentricity (1901-1939)

In Catalonia and Spain, the period between 1901 and 1939 was characterized by profound transformations in political, economic and social realities. A clear example is that of the unstable political situation. In fewer than 20 years, Spanish society witnessed a totalitarian regime (1923-1930), the establishment of the Second Spanish Republic (1931-1939), and the dramatic episode of the Spanish Civil War (1936-1939). Moreover, cities' transformations related to the social transformation into a mass industrial society represented perhaps one of the most important issues in Spanish society.

Since the 20th century, there has been an increasing concentration of the population in urban areas. Urbanization was coupled with social conflicts. First, the dominant urban development strategy of that time—namely, the strict grid pattern referred to as *Eixample*[2]—could not adequately mitigate the negative effects of large population concentrations (De Terán 1978; Roca 1979, 1983). These effects were caused not only by issues related to the hygiene and function of the deprived historical parts of the city but also by an increase in demand for housing, which became less affordable because of industrialization: grid development was costly. Consequently, lower social classes could not afford the housing prices caused by the *Eixample* model and were forced into the poor living conditions of the historical city centers. Second, social tensions arose from the appearance of marginal urbanizations at the edge of large cities and along the connections with minor centers. These scattered urban fragments were disconnected from the urban centers and had few urban facilities. Consequently, these social problems generated increasing doubts about the appropriateness of the urban grid as model for urban development, not only among the low-income households that were affected but also among a portion of the ruling social classes, who considered these social tensions a threat to political stability (Roca, 1983).

This situation set the stage for a fierce debate in Catalonia on the relationship between industrialization and cities. In this debate, some politicians and intellectuals supported by cultural movements, along with representative figures of social movements, insisted on the need for different solutions. The two camps took clear positions that translated into the formulation of opposing spatial planning proposals in approximately the 1930s (Lluch and Nel·lo, 1984; Pujol, 1997; Roca, 1977).

On the one hand, some considered the city a threat to both social and political stability because of the high concentration of workers in the capital city of Barcelona. This remarkable mistrust was characteristic for a portion of the *Lliga Regionalista* (Regionalist League), which was the political party that represented the interest of the Catalan industrial bourgeoisie. However, most of the important figures related to left-wing political parties (such as *Esquerra Republicana de Catalunya* (Republican Left of Catalonia)) and labor unions also adopted this perspective. Despite their very different ideas about many social issues, the two sides' common ground was the theory that the population concentration in Barcelona fostered its gigantism, which could lead to destabilizing the country, distorting and disorganizing the territory to such an extent that its existence was endangered. For instance, the geographer Pau Vila, who was close to the working-class movement and had republican ideas, warned about a long, unstable social situation in Catalonia caused by the massive concentration of immigrant workers into Barcelona (Vila, 1932). These concerns about Barcelona's gigantism were translated into an intellectual and cultural movement headed by the Catalan architect Cebrià de Montoliu. This movement was first connected to E. Howard and P. Geddes' (among others) planning

2 This was the name that received the first urban extension for Barcelona, designed by the planner Ildefons Cerdà in 1859. It was based on a grid pattern that was denominated *Eixample* and optimized to accommodate pedestrians, urban railway lines, gas supply and large-capacity sewers to prevent floods, without neglecting public and private gardens and other amenities.

ideas of *Garden-cities* and then were linked to the *American City Planning* of the 1920s to obtain a more comprehensive vision of suburban residential planning based on new towns or satellite cities, as envisioned by, e.g., the plan for Radburn, New Jersey, coined by Clarence Stein and Henry Wright. Its aim was to propose an alternative development strategy to make the city a place where the wealthy and the poor could live together, thus avoiding the spatial segregation problems that were so common in urban areas modeled upon *Eixample*. The influence of this movement on the planning debate was remarkably strong. For example, Cebrià Montoliu founded the *Societat Cívica la Ciutat Jardí* association and *Civitas* journal, both of which had the objectives not only to disseminate Howard's thoughts by depicting examples of *Garden-cities* (such as Letchworth, Welwyn, Hampstead, Bourniville and Port Sunlight in Britain (see Montoliu, 1913)) but also to advance new planning ideas focusing both on the problems of the industrial city and how new planning ideas could and should be conceptualized in Catalonia.

On the other hand, some took the position that advocated reinforcement of Barcelona's industrial role using the urban model of *Eixample*. This camp was heavily influenced by the models of the *Gross-Stadt*, which had been coined by international architects such as Tony Garnier, Walter Gropius and Le Corbusier (Roca, 1983). The ambition was to create a 'Great Barcelona' that paid tribute to the Catalan economy, would be its international calling card, and would further transform Barcelona into a top-ranking international city—just as cities such as Paris, New York and Berlin emerged during the 19th century. This position received the support of the mostly Catalan industrial bourgeoisie and the political leaders of the *Lliga Regionalist*a (Prat de la Riba or Puig i Cadafalch), along with other leading figures such as Barcelona's mayor, Carles Pi i Sunyer, and politician Antoni Rovira i Virgili, of *Esquerra Republicana de Catalunya* (Roca, 1976). The common idea was the belief that Barcelona's historical role had been less important than it could and should have been. As indicated by Rovira i Virgili (1926:563-564), "*what painfully impressed us… were the persistent complaints and accusations against Barcelona's centralism… Barcelona in the course of history has suffered more of* a *lack of ambition… than by the desire to centralize or absorb… all that someone can blame Barcelona for, will be nothing compared to what other cities in the same condition can be accused of*" [translation by the author].

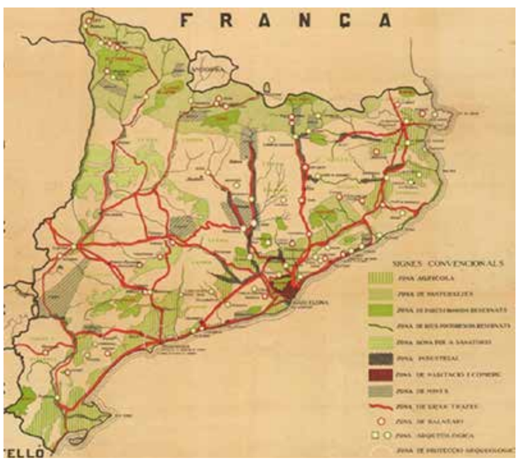
The 1932 Regional Planning: the first vision of polycentricity for Catalonia's territory

Translation of the criticism of Barcelona's increasing gigantism into specific spatial planning proposals first occurred in the 1932 *Pla de distribució en zones del territori català: Regional Planning* (Zoning Plan of the Catalan territory: Regional Planning), which was designed by architect Nicolau M. Rubió-Tudurí. The *Regional Planning* proposal's primary spatial concepts were closely linked to the planning ideas previously coined by Rubió-Tudurí at the XI National Congress of Architects (I Urbanism), held in Madrid in November 1926. At that congress, Rubió-Tudurí, who was the secretary of the *Societat Cívica la Ciutat Jardí*, developed the concept of *Regional Planning*. This concept, which exhibited some similarities to *American City Planning*, attempted to overcome the simplified contrasts between *Eixample* and *Garden-cities* and between compactness and rurality. Rubió-Tudurí's paper stated, "*the English have called the urbanization of the country 'Regional Planning'. The French refer to it as regional urbanization. Region would mean both county and great country depending on the case. But Regional Planning always wants to indicate that a widespread idea is applied to the whole territory… the regional urbanization means the peace treaty between the city and the countryside… the territorial development is proposed as the brake to the exaggerated attraction of the urban centers. Limit the agglomeration forces existing in the large cities through the only mechanism that is possible: the dissolution of the attraction of the city center throughout the country*" (Rubió-Tudurí, 1926a:1) [translation by the author].

In this regard, Rubió-Tudurí's paper proposes a decentralization doctrine based on the development of centers with limited growth to achieve the dissipation of the urban throughout Catalonia's territory.

Thus, the primary contribution of *Regional Planning* is the *urbanization of the country*. Essentially, Rubió-Tudurí (1926b) states that unlike the conceptualization of the city as an isolated center that is disconnected from its surrounding territory, the city should be understood in relation to the rest of the territory, the wider region or even the country. This perception probably influenced Gabriel Alomar's idea of *Catalunya-ciutat* (Catalonia-city), referring to a territorial model for Catalonia based on increasing the population concentration in several cities without disturbing the dissemination of culture, urban facilities, and urban lifestyles throughout Catalonia. Moreover, Rubió-Tudurí's doctrine could also have influenced majority opinion in Catalonia, as expressed though a questionnaire disseminated during that period (see Rovira i Virgili, 1926). The questionnaire showed not only that most Catalans felt the need for an adequate response to Barcelona's centralism and its absorbent nature but also that Catalans who did not live in Barcelona felt neglected.

Turning to the *Regional Planning* proposal, as Figure 3.1a shows, Rubió-Tudurí supported the decentralization of Barcelona's agglomeration to organize distinct human and natural activities throughout Catalonia. This vision attempted to transform Barcelona into the urban part of a future *Catalunya-ciutat* in which industrialization had fewer negative consequences (Cassasas, 1977; Nadal, 1991; Pujol, 1997; Roca, 1979). To achieve this goal, the proposal understood the city as one element of the landscape, with the following 12 activities identified as types of planning zones: agriculture; pasture; forest and parks; water; health care; industrial uses; residential and commercial uses; mines; communication; leisure; archaeological; and protected archeological.



A The 1932 Regional Planning

Source: ICC (Institut Cartogràfic de Catalunya).

B The 1936 Divisió Territorial de Catalunya

Source: Generalitat de Catalunya (1937).

FIGURE 3.1 The first planning visions of polycentricity for the entire Catalan territory

For example, Rubió-Tudurí distinguished among 6 functional zones in the areas surrounding Barcelona. First, he identified transportation zones both to decongest Barcelona and to connect it with the rest of Catalonia's urban settlements. These zones were located along Barcelona's northern settlements (Sant Cugat del Vallès, Cerdanyola del Vallès, Martorell, and Papiol) along the Llobregat (i.e., the river that delimits Barcelona's western boundary). Second, agricultural zones are also located along the Llobregat. Third, forest, parks, and protected natural spaces are distributed along the coast, the Llobregat and the Besós rivers (the latter delimits Barcelona's eastern boundary), and the mountain of Collserolla, which separates Barcelona from the aforementioned northern urban settlements. Fourth, there are residential areas that are located beyond Barcelona and linked to transportation zones. The definition of this functional zone could significantly illustrate the influence exerted by the *Garden-cities* movement. By locating new residential areas beyond Barcelona, Rubió-Tudurí could have attempted both to delimit Barcelona's growth and to mitigate the social tensions arising out of its negative externalities (e.g., unaffordable housing costs). Fifth, there are industrial and commercial zones centered on Barcelona's northern urban settlements (such as Sant Cugat de Vallès, Rubí, and Papiol) and on its adjacent cities (such as L'Hospitalet de Llobregat). With the decentralization of such activities, Rubió-Tudurí aimed to create new economic attraction poles linked to residential areas and thus, to encourage decentralization of the population from Barcelona. Sixth, there are airport and logistic zones located along the mouth of the Llobregat, in El Prat del Llobregat.

Rubió-Tudurí's ideas, particularly the 1932 *Regional Planning* proposal, can be regarded as the first appearance of what we would call a polycentric territorial development model. Planning ideas such as spatially balancing zones of activities (e.g., combining industrial and agricultural zones) and the decentralization of the capital city of Barcelona are closely related to the creation of new inter-connected economic and residential urban centers beyond Barcelona. Examples of these new centers that were functionally autonomous from the capital city of Barcelona included the cities of Sant Cugat del Vallès and Rubí, along with others such as Girona, Olot, Figueres, Vic, and Manresa (see Figure 3.1a). However, the *Regional Planning* proposal was never politically approved. One primary reason for its failure to win approval was its provisional, abstract nature and lack of supporting analysis. The then-unstable political situation in Catalonia/Spain, which led (for instance) to the suspension of l'*Estatut d'Autonomia* (the legal framework that gave autonomy to Catalonia) in 1934, also played a role because it became unclear whose responsibility it was to implement a polycentric planning vision.

The 1936 Divisió Territorial de Catalunya: the first application of polycentricity as an alternative development strategy

The second attempt to translate criticism of Barcelona's increasing gigantism into a spatial plan was the *Divisió Territorial de Catalunya* (Territorial Division of Catalonia) proposed by the geographer Pau Vila; that plan was adopted by the *Generalitat de Catalunya* in 1936. The *Divisió Territorial de Catalunya* organized Catalonia's entire territory into 38 geographical regions, referred to as *comarques*, into 9 supraregions called *vegueries*, see Figure 3.1b. The objective of this territorial organization was to define an administrative division for Catalonia that could represent the market relationships among its constituent parts. The work to elaborate the plan began in October 1931, when the *Generalitat de Catalunya* approved the creation of a commission referred to as the *Ponència d'estudi de l'estructura Comarcal de Catalunya* (Presentation of Study on the Regional Structure of Catalonia). This Commission elaborated four main principles to identify administrative units. First, the new territorial division should have a low number of regions. Second, the extension of each region should allow round trips between each city in the region and the capital within a single day. Third, there was need for a territorial administration on two distinctive scales—regions and supraregions—where the latter division should perform the functions of the *Provincias* (Provinces) established in 1833[3]. Fourth, there either should be a territorial balance among the distinct regions corresponding to their number of inhabitants or those regions should be extended to compensate.

In an effort to realize these four principles, a survey was carried out in November 1931 based on three questions. To which region do you think your town belongs? In which city do you go to the market? Do you go to any other market? The objective was to identify the primary *ciutat-mercats* (city-markets) of

3 There was an attempt by the *Generalitat de Catalunya* to eliminate this administrative division, which was approved in 1833 by the Spanish Government. As Oliveras (2009:190-191) states, the reason for this attempt was primarily political: the Catalan parties were complaining about the severe repression by the Civil Governor (Political Head of the *Provincias*) on the orders of Spain's government.

Catalonia and their roles to provide a backbone for the region's entire market structure (Generalitat de Catalunya, 1937). In this regard, the map resulting from the first question showed a variety of traditional names with a mix of regional concepts and localisms. The map resulting from the second and third questions, which covered all areas of market influences, showed functional relations caused by ease of commuting and historical commercial relations. On this basis and that of the popular denominations of the first map, the spatial plan of *Divisió Territorial de Catalunya* organized the identified markets, which can be conceptualized as functional economic regions, into the aforementioned 38 regions led by the capital city.

This territorial organization could point to a link between the polycentric notion of *Regional Planning* and the spatial plan of *Divisió Territorial de Catalunya*. Distinguishing 38 functional economic markets may be closely related to the planning concept of *urbanization of the country* based on the homogenization of the landscape, the decentralization of population and economic activity from the city of Barcelona and understanding a city as more than an isolated settlement. For example, it can be argued that the agglomeration forces in isolated large industrial cities could be reduced across the territory thanks to the establishment of this set of functional areas. Moreover, the proposal of the 1936 Territorial Division of Catalonia could also cause use to revisit the aforementioned concept of *Catalunya-ciutat* by identifying the leading cities of each region. In a sense, these regional capitals can be perceived as cities that can truly organize the Catalan territory in its entirety without hampering the Catalan population's urban lifestyle when they could also countervail the dominance of Barcelona.

Two other meaningful influences could be detected. First, the territorial division of Catalonia into administrative regions that proxied similar economic realities in the territory could be consistent with the international regional debate that was primarily disseminated since the early 20th century by the French geographer Paul Vidal de la Blache and his colleagues[4]. The main idea promulgated by these French geographers was that administrative divisions had not been adapted to the economic transformations at that time because economic dynamics had often occurred in supra-administrative territories. For example, Vidal de la Blache (1910) proposed the organization of the French territory as a set of homogenous regions (supra-administrative territories) headed by inter-connected urban centers by studying the landscape, rail networks and thematic cartography. Second, the Central Place Theory coined by Christaller (1933) may also have influenced the proposal of the *Divisió Territorial de Catalunya*. Central Place Theory essentially describes regions according to their one-way flows towards their central place. These central places are assumed to be the highest-ranking urban settlement in the region because they provide services for those living in the surrounding, lower-ranking cities, forming their own functional hinterland. Therefore, the ideas of a region defined by movements to and from its capital—and that these capitals can structure their entire regional economic market—therefore could have been particularly associated with the Central Place Theory.

The 1936 *Divisió Territorial de Catalunya* was approved by the *Generalitat de Catalunya* during the first weeks of the Spanish Civil War (1936-1939) (but consequently, it was never implemented); it could have constituted the first formalization in a spatial plan of a polycentric territorial model for Catalonia because it primarily advocated for an *urbanization of the country* in a balanced and decentralized way through the establishment of two main levels of hierarchy. The first level was composed of 38 central places with their own functional hinterlands; the second level was composed of those central places that were also identified as the main centers for each of the 9 supraregions mentioned above.

4 These new regional ideas had a direct influence on Pau Vila. He was a geography graduate of l'École des Sciences de l'Education in Ginebra, where the representative figure of the movement, P.Vidal de la Blanche, was then a professor.

The 1934 Pla Macià or Nova Barcelona: monocentricity to advance the generation of a national and international capital

As explained, there were opposing visions of future urban development that departed from a much more positive view of industrialization and what it meant for cities. This view was formalized in the *Pla Macià* designed by Le Corbusier and GATCPAC (*Grup d'Arquitectes i Tècnics Catalans per al Progrés de l'Arquitectura Contemporània*), an architecture movement established in Catalonia in 1926 with the goal of disseminating the international architectural ideas related to rationalism and functionalism that were gaining importance at the time. The Pla Macià was published by the journal *AC Documentos de Actividad Contemporánea* in 1934 (Le Corbusier and GATCPAC, 1934). Its primary objective was to transform Barcelona into a functional city in accordance with the capitalism model. That meant that the *Pla Macià* advocated the continued growth of Barcelona that began in the 19th century to further increase the city's consumer-service and metropolitan functions. The project built on the planning principles of organizing new urban extensions adjacent to the existing city following the *Eixample* model. However, it also introduced important modifications to the design of these extensions to mitigate the social issues arising out of large industrial cities. This is explained by Roca (1977:29), who stated as follows: "*Barcelona is thought as an industrial city which gives great importance to the working class and as a capital of an autonomous State…the Pla Macià is conceptualized as the plan of a functional city, as a plan of a working class city and, as a plan of a political capital*" [translation by the author]. These modifications, along with the spatial proposal of the Pla Macià, are presented in Figure 3.2.

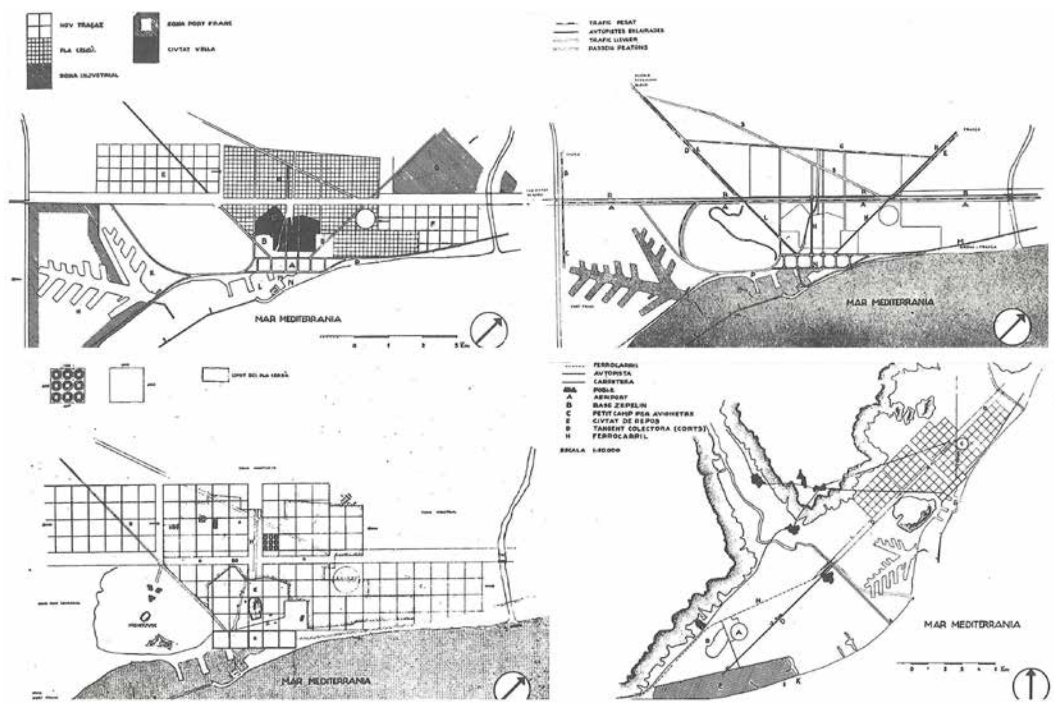


FIGURE 3.2 The 1934 *Pla Macià* proposed by Le Corbusier and GATCPAC (*Grup d'Arquitectes i Tècnics Catalans per al Progrés de l'Arquitectura Contemporània*)

Source: Le Corbusier and GATCPAC (1934).

Essentially, the *Pla Macià* foresaw an urban extension for Barcelona, which spilled over its geographical limits as defined by Llobregat and Besós rivers. This urban extension was based on four key planning characteristics. The first characteristic was the regeneration of the historical center of Barcelona through the demolishment and replacement of those deprived buildings by public facilities and green zones. The second characteristic was the development of an urban extension using the grid pattern designed by Cerdà (*Eixample*), but changing its original size of 113.3x113.3 meters to 400x400 meters, as shown in Figure 3.2 (bottom left), with the purpose of fostering distinct traffic speeds both within and between these enlarged units. The third characteristic was the creation of the *Ciutat de Repòs and Vacances* (Repose and Vacation City), which were located beyond Barcelona's limits but were well connected to its center through Gran Via avenue, as Figure 3.2 (bottom right) presents. With the creation of this satellite functional zone, the *Plan Macià* sought to accommodate affordable, working-class residential areas that could compensate for the high rents of the industrial cities. The fourth characteristic was the introduction of the zoning principle as an expression of the definition of the functional city's proposal for Barcelona. In this regard, the *Pla Macià* divided Barcelona into a business district zone located in the historical center, a governmental and civic zone, existing residential neighborhoods that referenced the current grid pattern using the *Eixample* unit, future residential neighborhoods with industrial zones located adjacent to the current *Eixample* grid, a commercial port, a tourist port, and an industrial zone distributed along the Montjuic mountain close to the port.

The monocentric nature of the *Pla Macià* proposal is particularly prominent with respect to two issues. The first issue builds on the planning ideas of Le Corbusier and is related to the spatial configuration of the business zone. These ideas were based on linking the locations of office buildings, which represented competition among large companies, to the design of the most intensive spaces in a city and thus, its city center. Le Corbusier (1924) notes that the country with the most rational city centers would have the highest probability to occupy the best position in international competition. In this regard, Barcelona's business zone was designed to accommodate two 170-meter towers for the services sector. The second issue was associated with the territorial delimitation considered by the 1934 *Pla Macià*. Despite the strong relationship between the *Grup d'Arquitectes i Tècnics Catalans per al Progrés de l'Arquitectura Contemporània* and the international architecture movement[5], the planning territory was exclusively defined by the areas surrounding Barcelona. These planning boundaries clearly contradicted the concept of *regió-ciutat* (region-city) introduced by Josep Lluís-Sert (member of the *Grup d'Arquitectes i Tècnics Catalans per al Progrés de l'Arquitectura Contemporània*) and later presented at the V CIAM (International Congresses of Modern Architecture) Congress in 1937. More specifically, Sert (1937) states that like the idea of an organic city with four functions (residential, work, recreation, and transport) expressed in the Athens Charter, the city and the region also form a unit based on their economic, social, and cultural relationships that appear when the city extends its limits. However, as the letters between Josep-Lluís Sert and Le Corbusier show (see Tarragó, 1972), the elaboration of *Pla Macià* had only limited interest in the regional scale and its related planning implications. Therefore, it can be argued that the monocentric nature of the plan was reinforced because the *Pla Macià* only covered the territory of Barcelona and its immediate surroundings, thus neglecting the regional scale.

Finally, like the 1932 *Regional Planning*, the 1934 *Pla Macià* was not approved. Although the plan was supported by the then-ruling *Esquerra Republicana de Catalunya*, that party's considerable loss of political power during the Spanish Civil War destroyed any possibility of approval.

5 Evidence of this strong relationship includes the March 1932 meeting of the CIRPAC (International Committee for the Realization of Contemporary Architecture) in Barcelona, which aimed to prepare the IV Congress on the Functional City. The conclusions of that congress, which was organized by *Grup d'Arquitectes i Tècnics Catalans per al Progrés de l'Arquitectura Contemporània*, were to adopt distinct spatial planning formulations (internationally known as the Athens Chart) for the city.

§ 3.3 Visions of polycentricity during the dictatorship (1939-1976)

After the end of the Spanish Civil War in 1939, most of the leading figures that had led the planning debate in Catalonia since the early 20th century had to migrate abroad because of their connections with the political and social bloc that lost the war. This implied that during the totalitarian regime, planning practice acquired an important disciplinary nature that was disconnected from any type of cultural or social movements and thus, the primary actors developing spatial plans in Catalonia tended to be (planning) professionals.

In this regard, 1939 marked the beginning of the development of a strategy organized by the *Servicios Técnicos de la Falange* (Technical Services of the Falange)—the professional services of the totalitarian regime—with the aim to define a framework for the future elaboration of the *Plan Nacional de Urbanismo* (National Urbanism Plan) at the Spanish level. A plan was developed through the creation of several governmental institutions and the organization of many academic conventions to determine planning ideas. In terms of the newer authority institutions, it is important to single out the *Jefatura Nacional de Urbanismo* (National Urbanism Headquarters), founded in 1949, which represented the main urbanism authority until 1957, when it was replaced by the *Ministerio de la Vivienda* (Ministry of Housing) with the purpose of combining the administrative competences of housing, architecture and urbanism into a single governmental department. With respect to the development of the main planning ideas, the 1939 *I Asamblea Nacional de Arquitectos* (National Convention of Architects) in Madrid and the 1959 *Congreso Nacional de Urbanismo* (National Urbanism Congress) in Barcelona stand out because of their prominence. For example, during these conventions planning objectives were formulated, such as the need to achieve an urban regeneration of cities' historical centers and the prevention of excessive urban growth as a way to achieve a balanced territory.

These planning concepts, influenced to some extent by internationally debated ideas such as the multinuclear city to replace the old, dense urban masses (Mumford, 1938), organic decentralization through a set of compact cities with green belts (Saarinen, 1943), and urban fragmentation to create satellite towns (Abercrombie, 1945), ultimately formed the key planning concepts applied in the spatial plans developed during the first decades of the Spanish dictatorship. Evidence of this development includes the books of the architect Alomar (1947, 1955) that were published by the *Instituto de Estudios de Administración Local*, which was the organization with primary responsibility for performing the tasks of research, teaching, and academic dissemination in Spain at that time. For instance, Alomar (1947) advocates the development of an organic nucleation (*nucleización orgánica*) by applying a decentralization strategy to achieve a better balance between urban and rural areas and thus, to mitigate the negative consequences of industrialization on urban centers.

After its first twenty years, the totalitarian regime entered an economic growth phase that accompanied increasing migration from the countryside to cities because of increased employment opportunities in the industrial and the service sectors (De Terán, 1978; Saiz, 2006). One of the primary drivers of this changed economic perspective in Spain was the dictatorship's 1959 approval of the *Plan de Estabilización* (Stabilizing Plan). This plan was primarily based on a set of liberal and austere policies such as currency devaluation and reduced intervention in the economy. These policies could have been translated into the planning discipline (and practice) at that time as a strong motivation to accept the territorial dynamics that aim to restrict the urban growth in central agglomerations, which had been one of the totalitarian regime's primary spatial concepts since 1939. Motivation to accept—not restrict—urban growth, which could also have been reinforced by the appearance of novel spatial concepts during the 1960s in studies such as Hall (1966) or plans such as the 1963 *Piano Intercomunale Milanese* (Milan Inter-Municipal Plan) and the

1965 *Schéma Directeur d'Aménagement et d'Urbanisme de la Région de Paris* (Director Scheme of Urban Planning and Development for the Paris Region), collectively aimed to cast doubt upon the concentric model of green belts and satellite cities for constraining the congestion and growth of the central agglomeration. These new spatial concepts were primarily based on three key points. The first point was the acceptance of urban growth as an opportunity to organize a territory. The second point was the establishment of a tangential transport infrastructure model to connect existing centers with urban areas of new growth. The third point was the definition of polycentric structures to ameliorate urbanization pressure on the center of an agglomeration. The influence of these two factors strengthened to the point that they led to a change in Spain's spatial planning concepts. The evidence of such change first became apparent in Catalonia's post-1959 planning proposals. Next, the spatial plans elaborated during these two distinct historical periods of the Spanish dictatorship will be explained.

The 1953 Pla Comarcal d'Ordenació Urbana de Barcelona: a failed attempt

The *Pla Comarcal d'Ordenació Urbana de Barcelona* (Regional Plan for the Spatial Planning of Barcelona) was approved in 1953 under the supervision of the *Jefatura Nacional de Urbanismo* and was designed by a technical team belonging to the *Comisión de Urbanismo de Barcelona* (Urbanism Commission of Barcelona), which was led by architect Josep Soteras Mauri. This plan's planning objectives were closely related to the totalitarian regime's 1939-1959 planning doctrine and therefore, it presented a polycentric development strategy as an alternative to the process of metropolitanization based on limiting the growth of the central city. This polycentric alternative can be seen in the report of the spatial plan (Comisión Superior de Ordenación Provincial y Oficina de Estudios del Ayuntamiento de Barcelona, 1954:5), which noted as follows: "*...the need to establish a set of organic communication systems...the foreseen of growth and development...lead to the need for a Regional Plan that organize Barcelona and their surroundings. The Plan studies the limits of the urban growth in a nuclear way, avoiding the unlimited extension of the metropolis and developing independent centers with their own nature*" [translation by the author].

The territory delimited by the 1953 *Pla Comarcal* was the region (*comarca*) of Barcelona defined by Barcelona (the capital city) and its 27 municipalities (see Figure 3.3). Essentially, the aim of this plan was to guarantee the region's territorial balance, which was to be achieved through the application of a decentralization strategy focused on a set of centers (see Figure 3.3b). Each center was supposed to maintain its own characteristics not only because appropriate zones were established to distinguish between residential and industrial areas but also because of the preservation of open spaces (see Figure 3.3a). In this regard, the *Pla Comarcal* defined a decentralization scenario with a horizon growth scenario that would imply 2.4 million inhabitants for the city of Barcelona and 4 million inhabitants for the entire *comarca* by 2000. This population development scenario was also translated into a zoning proposal of the plan based on 39 zones classified into 6 groups following specific density levels. The first density level included residential zones (e.g., the historical center with 700 inhabitants per hectare, the intensive *Eixample* with 900 inhabitants per hectare, and the extensive garden-city development with 200 inhabitants per hectare). The second density level included residential-industrial zones (400 inhabitants per hectare). The third density level included industrial zones. The fourth density level included special zones (e.g., commercial, sanitary, or leisure zones). The fifth density level included park zones (e.g., urban or forest parks). The sixth density level included the countryside (e.g., rural, agricultural or forest zones). According to the *Pla Comarcal*, the decentralization scenario and its related zoning proposal should enable the establishment of civic, commercial and industrial centers in distinct cities, and consequently, should prevent the coalescing of those municipalities near the capital city of Barcelona (preventing them from become mere neighborhoods of Barcelona).

A *Zoning* *B* *Structure*

Source: Martorell et al. (1970), adapted from the Comisión Superior de Ordenación Provincial y Oficina de Estudios del Ayuntamiento de Barcelona (1954).

FIGURE 3.3 The 1953 *Pla Comarcal d'Ordenació Urbana de Barcelona*

In a sense, this organic-functional conceptualization of the *Pla Comarcal* could be linked to the aforementioned principles of the functional city disseminated by the *Grup d'Arquitectes i Tècnics Catalans per al Progrés de l'Arquitectura Contemporània* and applied in the 1934 *Pla Macià*. Another connection between the principles of the *Pla Comarcal* and those of the *Grup d'Arquitectes i Tècnics Catalans per al Progrés de l'Arquitectura Contemporània*'s is the planning territory considered by the *Pla Comarcal*. It adopted a regional scale as the territorial scale for which it was necessary to define a polynuclear scheme to avoid the negative effects of Barcelona's agglomeration. This concern about territorial dynamics with respect to the supracity scale was closely related to the aforementioned concept of region-city (Sert, 1937), although as previously mentioned, neither Sert nor Le Corbusier considered this link between Barcelona and its urban surroundings in the elaboration of the *Pla Macià*. The links between the *Pla Macià* and the *Pla Comarcal* therefore indicate a connection between the planning ideas before the Spanish Civil War and those ones applied by the totalitarian regime.

However, two points reveal that the *Pla Comarcal* should be understood as a failed attempt to develop a polycentric territorial model. First, in practice, the vast majority of the population would still be concentrated in the city of Barcelona: it was projected that almost 3.2 million of the expected 4 million residents (by 2000) would reside in the city. This shows that the *Pla Comarcal* did not propose clear alternatives that would truly diminish the congestion of the central urban agglomeration. Indeed, only the cities of Sant Cugat del Vallès (224,928 inhabitants) and Cerdanyola del Vallès (165,126 inhabitants) were considered as important new growth centers. Second, because the *Pla Comarcal* did not consider other important centers beyond the region of Barcelona such as Terrassa, Sabadell, Rubí, Granollers, or Mataró, its polycentric proposal could exert only a limited influence to balance Barcelona's central agglomeration. Therefore, it can be argued that if the *Pla Comarcal* aimed to define a truly polycentric reality for Barcelona, it should have considered a larger, regional scale that was more closely related to the supraregion of Barcelona defined by the 1936 *Divisió Territorial de Catalunya* than to the territory planned by the 1934 *Pla Macià*. That said, the next plan discussed in this thesis considered a larger territory (the province level), a difference that (to some extent) addresses this concern.

The 1959 Pla General d'Ordenació de la Província de Barcelona: the polycentric vision of the Divisió Territorial de Catalunya applied at the provincial level

In 1959, the *Pla General d'Ordenació de la Província de Barcelona* (General Plan for the Spatial Planning of the Barcelona Province) was proposed by architects Pedro Bidagor and Manuel Baldrich under the supervision of the *Ministerio de la Vivienda*. They defined the urban developments' organic structure, a specific zoning (functional) proposal for the land and a set of regulations to accurately implement the plan (Ministerio de la Vivienda, 1959:122-126). These three planning purposes were related to the achievement of three general planning objectives posed by the *Pla Provincial*: balanced provincial development through the definition of a *comarcal* system ('system of regions'), improvement of human-habitat conditions, and protection of the natural landscape (see Figure 3.4).

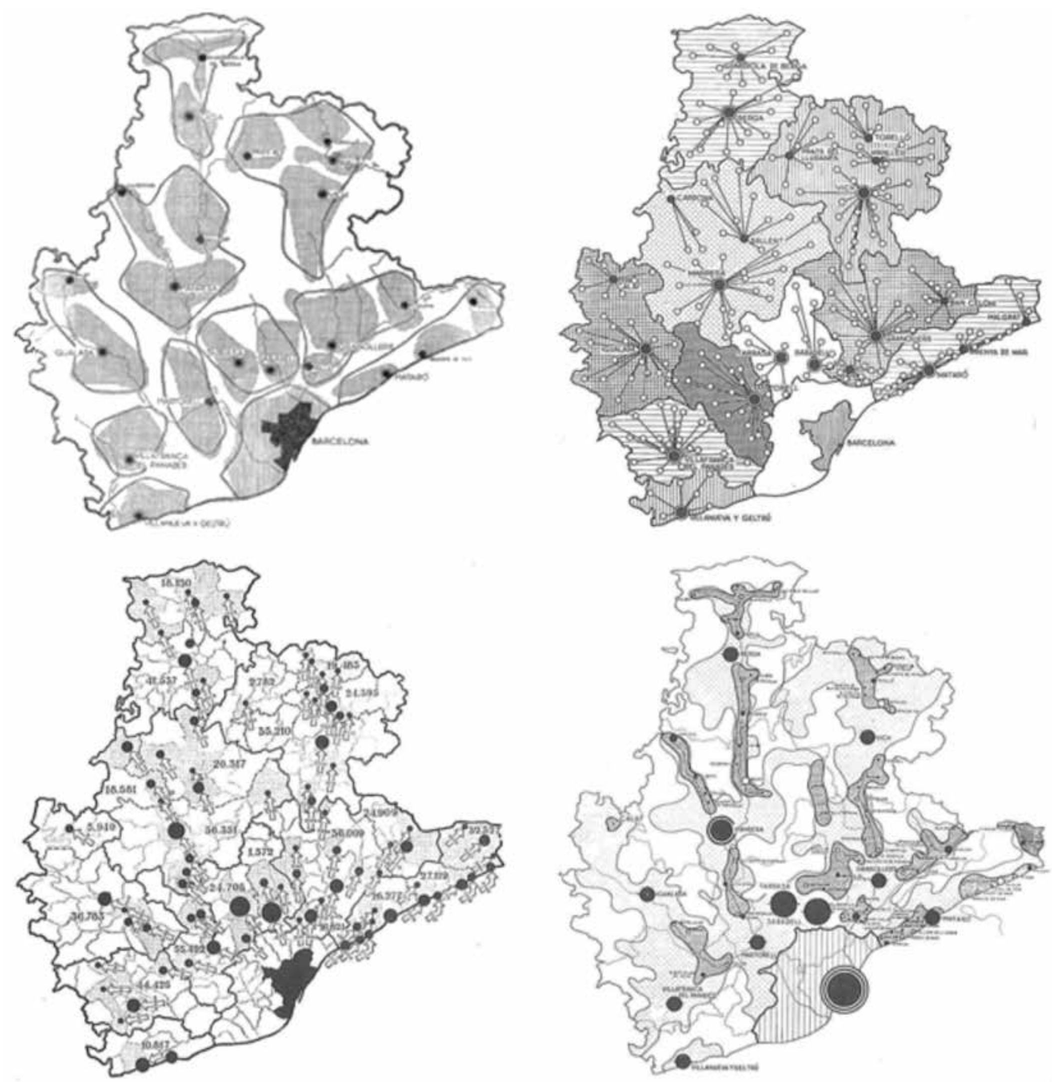


FIGURE 3.4 The 1959 *Pla General d'Ordenació de la Província de Barcelona*

Source: Ministerio de la Vivienda (1959).

The achievement of the first general planning objective, which reveals the *Pla Provincial*'s polycentric vision, relied on the accomplishment of 19 specific objectives, the five most important of which were the following. The first objective was to develop an urban structure based on the *comarques* (regions) within the province, conditioned by the existence of Barcelona as a regional and provincial center (see Figure 3.4, top-left and right). The second objective was to limit growth in the city of Barcelona. The third objective was to regulate Barcelona's industrial concentration and to promote industrial growth in other zones to reduce Barcelona's capacity to attract population (see Figure 3.4, bottom right). The fourth objective was to regulate and orient migration flows within the province by applying decentralization measures (see Figure 3.4, bottom left). The fifth objective was to identify urban settlements that could become the capital of each region in the province.

The *Pla Provincial*'s formal conceptualization of a spatial organization for Barcelona at the province level and not at the territorial scale referred to Barcelona's urban surroundings, as proposed by the *Pla Comarcal*, had already been described by Manuel Baldrich, one of the two authors of a 1952 article describing the plan. Baldrich develops the concept of *ciutat-comarca* (city-region) as a proposal to decentralize urban development away from the main urban agglomerations to achieve balanced urban development. In this regard, Baldrich (1952:22) argues as follows: "*…a city-region is constituted by several urban communities of 5,000 to 10,000 inhabitants linked to a regional capital with 25,000 to 50,000 inhabitants…in each supraregion, formed by an integrated a set of smaller regions, a single urban center whose population can range from 100,000 to 200,000 inhabitants as a maximum could be identified. Surrounding these metropolises, a ring of between 50 to 100 kilometers needs to be created to avoid the growth of these agglomerations…the most of the new industries would be moved beyond this ring*" [translation by the author]. This makes the link between the *ciutat-comarca* idea applied in the *Pla Provincial* and the polycentric vision of Catalonia defined by the 1936 *Divisió Territorial de Catalunya* quite obvious. Baldrich (1952) also promotes decentralization and a better territorial balance by considering the region (composed of a capital and its functional hinterland) as the most suitable territorial scale for an administrative unit to develop a socioeconomic plan.

Consequently, with this idea of *ciutat-comarca*, the polycentric territorial model of the *Pla Provincial* was formalized in 11 regions that were composed of centers and the municipalities that form their hinterlands (see Figure 3.4, top left and right). In this regard, the *Pla Provincial* proposed an urbanization model based on groupings of urban settlements with 50,000 inhabitants separated by 20 to 50 kilometers, organized into one or two first-order centers, additional second-order centers, and a ring of towns of 5,000 inhabitants (Ministerio de la Vivienda, 1959:130). Moreover, each urban settlement in this group of cities received a functional classification to achieve the desired relationship between urban and rural areas, mimicking either the 1932 *Regional Planning* or the 1936 *Divisió Territorial de Catalunya*: industrial (mainly preferential, or proper), agricultural (industrial, ranching, or less favorable), forestry, and residential (and agricultural or industrial). This functional classification, together with the polycentric model of *ciutat-comarca*, therefore defined the spatial development strategy to achieve a balanced distribution within the Province of Barcelona.

In a sense, this polycentric territorial model could still be understood more as a development strategy to compensate for the dominant role played by Barcelona than as a strategy to organize and canalize urban development, which would have implied the promotion of a novel planning vision that perceived urban growth as an opportunity. The demographic study of the *Pla Provincial* (see Figure 3.4, bottom left) predicted a future population of more than 4.1 million in Barcelona and its surroundings by 2000, whereas almost 1.2 million people would live in the remainder of the Province of Barcelona. In other words, Barcelona's dominance would be strengthened if the plan's development strategy were unable to change these (largely migration) trends. To counter this trend, the *Pla Provincial* proposed a scenario to limit the population of Barcelona and its region to 3 million inhabitants (with the population of the rest of the province limited to 1.7 million) by 2000. Moreover, it emphasized the future roles of Sabadell, Terrassa, and Manresa, which would become major centers outside of Barcelona, with more than 150,000 inhabitants. Ultimately, however, the *Pla Provincial* was not approved. The approval of the *Plan de Estabilización* plays a role. The restrictive nature of the *Pla Provincial* and its decentralization strategy would have required powerful intervention by the public administration, thus contradicting the main principles of the 1959 *Plan Estabilización*'s economic policies of liberalization. Consequently, the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona* attempted to achieve a polycentric development that was less based on governmental intervention, as set forth.

The 1966 Pla Director de l'Àrea Metropolitana de Barcelona: a polycentric vision to canalize and organize urban developments

Considering that the demographic trends elaborated by the 1953 *Pla Comarcal* were completely inaccurate within ten years of approval, both because of its inaccurate predictions and because of the process of population and industrial growth since the 1950s, a Commission was formed in 1964 to revise the plan. In 1966, the *Comisión de Urbanismo de Barcelona*, headed by the architect Josep Maria Ros Vila, approved the working documents of that revision under the name *Pla Director de l'Àrea Metropolitana de Barcelona* (Director Scheme of the Barcelona Metropolitan Area). The novelties of this spatial plan are reflected in its name. First, the term *Pla Director* (Director Scheme) is not a type of plan[6] according to the *Ley del Suelo* (Land Regulation) approved in 1956, a fact that can be interpreted as an attempt to underline the lack of legal plans to adequately address Spain's urban reality during the 1960s. Second, the term Àrea Metropolitana (Metropolitan Area) is used for the first time. It refers to a metropolitan territory that was delimited using geographical, demographic, economic and planning criteria[7] to determine its functional relationships and interdependencies, but that was not yet an administrative unit.

In addition, some planning-decision novelties can be found in the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona* (see Figure 3.5a), which adopted the *città-regione* model proposed by De Carlo (1962) during the Stresa Congress in 1962 and applied in the 1963 *Piano Intercomunale Milanese*. This model was based on three main spatial ideas. The first idea was that the urban organization was no longer dominated by a single city but instead, that a metropolitan area should be understood as consisting of a plurality of centers with non-hierarchical relationships. The second idea was that the city and its hinterland form a single, inter-related space. The third idea was that a metropolitan territory should be conceptualized as dynamic instead of static in terms of its economic, social and spatial relations. Another novelty was that the model considered an enlarged territory beyond administrative boundaries, following the example of the 1965 *Schéma Directeur d'Aménagement et d'Urbanisme de la Région de Paris* (see District de la Région de Paris, 1965). The metropolitan area that required planning included 160 municipalities in seven regions (Barcelonès, Maresme, Vallès Oriental, Vallès Occidental, Baix Llobregat, Garraf and, Alt Penedès), defined by using the delimitation method described above[8].

Among the objectives of the 1966 *Pla Director*, the following 6 planning objectives stand out as best describing its planning vision and territorial model. The first objective is to use city growth as an instrument for defining the spatial development strategy. The second objective is to achieve social and economic homogeneity among cities. The third objective is to reduce congestion in residential, industrial and service areas, particularly those located in Barcelona. The fourth objective is to acknowledge both that the Plan acts as a flexible framework that allows changes and that planning should be a cyclical process. The fifth objective is to consider both the current urban centers and those that had been fused

6 The types of plan defined by the *Ley del Suelo* were as follows: *Plan Nacional* (National Plan), *Plan Provincial* (Provincial Plan), *Plan General de Ordenación Municipal o Comarcal* (General Plan for Municipal or Regional Development), *Plan Especial* (Special Plan), *Plan Parcial* (Sectoral Plan), and *Proyecto de Urbanització́n* (Urbanization Project).

7 The criteria defined by the Comisión de Urbanismo de Barcelona (1966, Vol.1:31-32) were as follows: earlier population growth rates (1950-1960 and 1960-1963), population density in 1960, daily traffic intensity to Barcelona, train frequency, bulk of residence-to-work flows to Barcelona, location of commercial areas, administrative divisions of the regions, main public transportation zones beyond Barcelona (30-60 minutes), topography conditions, planning needs (reserve of developable land), and administrative considerations (i.e., the exclusion of those municipalities outside the Province of Barcelona).

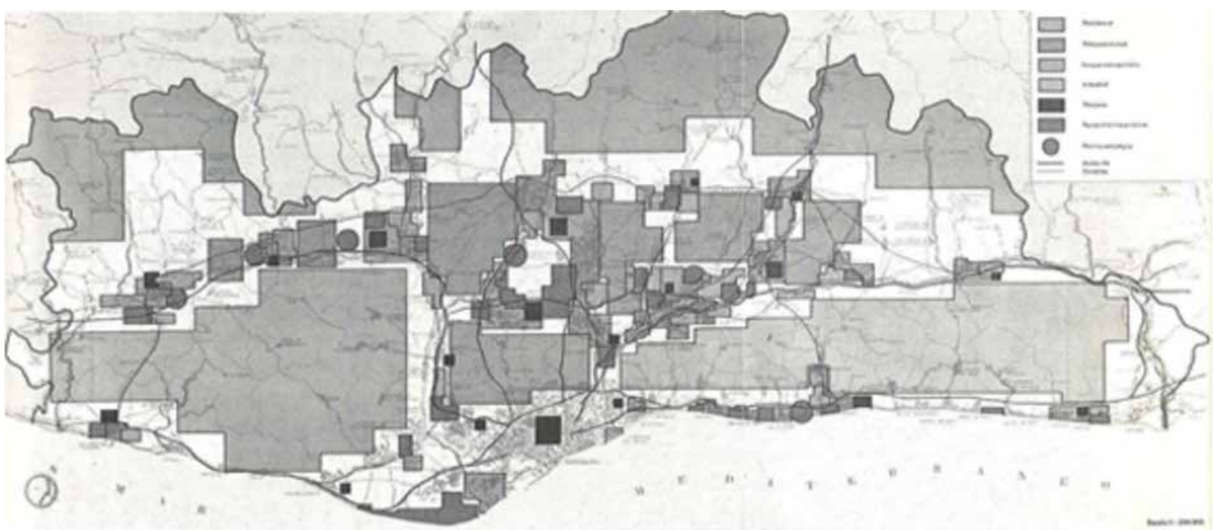
8 This delimitation of the *Pla Director de l'Àrea Metropolitana de Barcelona* can be equalized with supraregion I (Barcelona), plus the regions of Alt Penedès and Garraf that were previously defined by the 1936 *Divisió Territorial de Catalunya*.

by the urbanization dynamics to define the urban settlement proposal. The sixth objective is to establish a grid pattern of infrastructures that is homogenously distributed across the territory.

These objectives form the basis for the territorial model proposed by the *Pla Director* and its vision of polycentricity based on the development of a polycentric and decentralized structure. This structure would not neglect the importance of the centers and advocates balancing their social and economic interactions: "*the system shall promote the social, economic and spatial homogeneity of the territory... and the system that guarantees the achievement of these standards for all the territory, only can be based on a polycentric structure spread out over the metropolitan territory*" (Comisión de Urbanismo y Servicios Comunes de Barcelona y otros Municipios, 1966 Vol.2:50) [translation by the author]. More specifically, the polycentric vision the 1966 *Pla Director* was elaborated in the following three proposals regarding urban settlements and infrastructure.

A The proposal of the Comissió de Urbanisme de Barcelona in 1966

Source: Comisión de Urbanismo y Servicios Comunes de Barcelona y otros Municipios (1966).



B The alternative proposal of the Comissió Gestora de l'Àrea Metropolitana in 1974

Source: Ministerio de la Vivienda (1974).

FIGURE 3.5 The *Pla Director de l'Àrea Metropolitana de Barcelona*

The first proposal involves the creation of new centers and the reinforcement of others. For instance, the reinforcement of centers beyond the central city of Barcelona was primarily based on promoting a concentration of economic activities within them, which could also diminish congestion along the radial transportation axis towards Barcelona. Overall, the *Pla Director* planned a set of 11 centers beyond Barcelona with an optimal size of approximately 250,000 inhabitants by 2010, separated by open spaces and connected to the transport infrastructures (see Figure 3.5a). These centers were the municipalities of Sabadell, Terrassa, Martorell, and Granollers (300,000 inhabitants); Vilafranca del Penedès, Sant Sadurní d'Anoia, Mataró and Sant Celoni (250,000 inhabitants); Sant Cugat del Vallès (150,000 inhabitants); and Molins de Rei and Arenys de Mar (100,000 inhabitants). It is also important to note that the *Pla Director*, as Solà-Morales (1972:26) states, established distinct economic roles for the centers to enhance the economic complementarity among them, thus strengthening the polycentric structure of the proposal: "*They should play different roles, ones would have directly an economic propellant nature, others a particular specialization (transport, trade, administration) and the rest would accomplish the specific function of revitalizing the deprived and underserviced zones*" [translation by the author].

The second proposal involves the creation of second-service centers denominated *Centres Direccionals* (Directional Centers) and formed by an agglomeration of public facilities, personal services, commercial uses, and infrastructure facilities (i.e., parking lots, stations). These centers, of which one of the most important was located at Cerdanyola del Vallès, functioned to strengthen other centers (e.g., Sant Cugat del Vallès) by concentrating the aforementioned service activities at the limits of urban continuums and organizing the metropolitan territory by absorbing service activities located in congested cities, particularly in Barcelona.

The third proposal involves the implementation of a tangential transport infrastructure model. This infrastructure model, as opposed to the concentric (radial) model of green belt and satellite cities, was intended to create a more balanced metropolitan area by limiting the congestion and growth of the central city. Moreover, it aimed to follow the agglomeration's predicted growth tendencies to accurately canalize and organize future growth, mimicking the 1965 *Schéma Directeur d'Aménagement et d'Urbanisme de la Région de Paris* mentioned above. One of the best examples of this goal was the planning of a highway parallel to the coast (B-30) that would link all of the centers north of Barcelona (see Figure 3.5a) and promote the emergence of a large urban agglomeration that would be functionally independent from the central city of Barcelona.

Whereas the previous plans (e.g., the *Pla Comarcal* and *Pla Provincial*) proposed a polycentric structure by neglecting growth and introducing static, strict maximum city sizes, the *Pla Director* used decentralization as the point of departure and attempted to canalize urban growth to locations (centers, new centers and second-service centers) that could best absorb urban dynamics through the use of a tangential transport infrastructure model that linked them. This is the primary change introduced by the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona* regarding the definition of a polycentric territorial vision.

Nevertheless, the process for approving the *Pla Director* encountered serious difficulties that hampered its final approval. The delimited metropolitan area (approximately 3,000 square kilometers) far exceeded the territory in which the *Comisión de Urbanismo de Barcelona* had jurisdiction (the region of 485 square km defined by the 1953 *Pla Comarcal*); therefore, that metropolitan territory was also under the jurisdiction of the Province of Barcelona. This led to the *Ministerio de la Vivienda*'s decision to suggest a simultaneous revision of the *Pla Comarcal* and the *Pla Provincial* in accordance with the principles of the *Pla Director*. This revision process resulted in the completion of a second version of the *Pla Director* in 1974 (see Figure 3.5b), pending approval until the passage of a regulation would recognize Spain's metropolitan areas by conferring administrative jurisdiction. This occurred in 1975, when the *Ley de Régimen Local* (Regulation of the Local System) was approved. With this regulation, another administration level denominated as *Entidades Municipales Metropolitanas* (Metropolitan Municipalities Entities) was created with the goal of organizing the intermunicipality relationships that had resulted in the formation of metropolitan realities. Surprisingly, however, the delimited 'metropolitan' territory in Barcelona over which the *Entidad Municipal Metropolitana* ultimately had legislative jurisdiction was much smaller, covering only the territory in which the revision of the *Pla Comarcal* had been occurring since 1966, following approval of the *Pla Director*'s working documents. These processes finally culminated in the 1976 approval of the *Pla General Metropolità de Barcelona* (Metropolitan General Plan of Barcelona), which addressed only the 27 municipalities in the Barcelona region, not the 'real' metropolitan territory delimited by the *Pla Director*.

The 1976 Pla General Metropolità de Barcelona: another failed attempt

The approval of the revision of the *Pla Comarcal*, which was designed by the architect Joan Antonio Solans and the engineer Albert Serratosa, occurred in 1976; the revision was called the *Pla General Metropolità de Barcelona*. This plan adopted some spatial planning ideas from the *Pla Director de l'Àrea Metropolitana de Barcelona*, as presented in Figure 3.6. First, the plan advocated for sectoral specialization and economic complementarity between cities and urban areas; the specialization and complementarity were implemented by indication zones that were earmarked for a particular type of development. These earmarks included not only industrial zones (marked in blue in Figure 3.6) but also zones for transforming existing land use (marked as lightest green), zones for urban densification to foster urban renewal (marked in light orange), and zones for preserving the current urban structure (marked in dark orange). Second, the plan proposed the creation of five *Centres Direccionals* (Sant Cugat del Vallès-Cerdanyola del Vallès, El Prat de Llobregat, Sant Joan Despí, Sant Andreu-Meridiana, and Provençana-Litoral) as strategic centers for absorbing the decentralization of certain service activities and the achievement of a more even distribution across urban centralities. The main spatial concept of the *Pla General Metropolità,* mimicking the *Pla Director*, was therefore that Barcelona and its area of influence would become less monocentric and that the negative effects related to the existence of a single and absolute urban centrality were mitigated as a result of the promotion of alternative service centers.

Nevertheless, the fact that *Pla General Metropolità de Barcelona* did not consider Barcelona's total metropolitan territory meant that the ambition to transform Barcelona's region into a polycentric structure could not materialize. Perhaps the pressure to approve a new spatial plan that overcame the deficiencies of the previously approved plan (*Pla Comarcal*) was stronger than the desire to implement polycentricity on a larger scale, as envisaged in the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona*. The application of the polycentric vision of the *1966 Pla Director*, however, could have implied approval of the first metropolitan and supramunicipal plan that could have been able to implement the accumulated knowledge of the polycentric theoretical body, which dated from before the Spanish Civil War in the 1932 *Regional Planning* or the 1936 *Divisió Territorial de Catalunya* and continued during the dictatorship with the failed attempt of the 1959 *Pla Provincial*.

Consequently, after 35 years of totalitarianism, no plan was approved that supported a truly polycentric territorial model. Perhaps the lack of the required political support (e.g., *Pla Director de l'Àrea Metropolitana de Barcelona*) or the inability of some spatial plans to make accurate predictions of the nature of urbanization dynamics (e.g., *Pla Comarcal*), which would have avoided the need to constantly revise plans, could be the primary reasons for explaining the difficulty of coming to a political agreement on a polycentric development strategy. This observation implies that the planning debate on the territorial organization of Barcelona and Catalonia, which began in the early decades of the 20th century, continued.

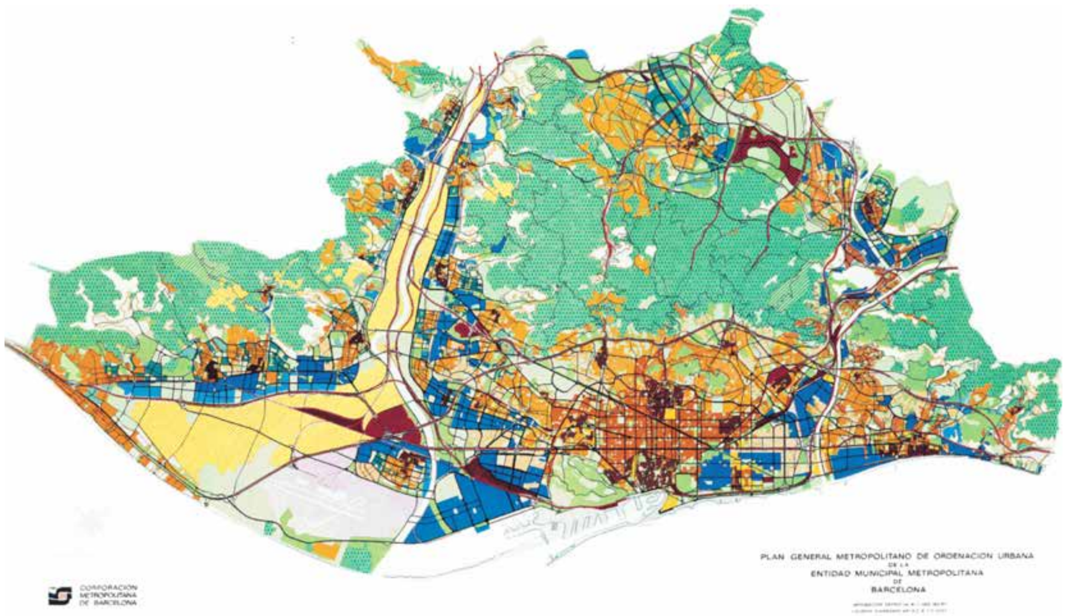


FIGURE 3.6 The 1976 *Pla General Metropolità de Barcelona*

Source: Corporación Metropolitana de Barcelona (1976).

§ 3.4 The polycentric vision and the territorial model after the restoration of democracy (1976-2010)

With the arrival of democracy in 1976, the *Generalitat de Catalunya* was restored, implying the recovery of autonomy, including exclusive competences in regional planning. Thus, new and real opportunities arose to organize the territory and its administrative division in a more effective way. In parallel, important cultural and social movements became very visible and influential again in Catalan society after having been silent during the dictatorship because of their association with the ideas and social classes that had been defeated during the Spanish Civil War. One example is the celebration of the *Congrès de Cultura Catalana* (Congress of Catalan Cultural) in 1976 and subsequent years. At that congress, professionals from a range of disciplines (architects, engineers, geographers, economists, etc.), politicians from across the political spectrum and representative figures from social movements participated, all insisting on the need to defend and promote Catalan culture. The 1978 resolutions of the Congrès de Cultura Catalana regarding the territorial organization are particularly relevant. These resolutions included a prominent claim for diminishing territorial disparities through the approval of an alternative administration division that implied the disappearance of the provincial structure, thereby enabling the promotion a new territorial model for the entire Catalan territory (see Congrès de Cultura Catalana, 1978). These demands for a new territorial organization were deeply rooted in Catalan society. As Cassasas (1977) and Lluch and Nel·lo (1984) note, even during the dictatorship there was a collective imagination in Catalonia that the *comarques* (regions) were the territorial organization that could have achieved a more balanced territory because they were administrative divisions delimited by economic relationships that could allocate similar number of inhabitants and urban functions.

Moreover, these demands found support in urbanization process of that period, which made it realistic to adopt alternative territorial development strategies. Compared to the metropolitanization process during the 1950s and 1960s based on a tremendous concentration of population and economic activities in the capital city of Barcelona, the urbanization trend since 1975 had primarily been characterized by a process of decentralization over the rest of the territory, which resulted in Barcelona and some other major cities experiencing important population losses (Font, 2005).

From the political dimension, the possibility of addressing the question of Catalonia's administrative division and its related territorial model emerged after the first elections to the Catalan Parliament in 1980. The liberal Christian democratic coalition of *Convergència I Unió* headed by Jordi Pujol won the most seats and formed a government. In 1983, Pujol's government approved the *Llei de Política Territorial* (Regulation of Territorial Policy), which ordered an elaboration of the *Pla Territorial General de Catalunya* (General Territorial Plan of Catalonia) and a set of *Plans Territorials Parcials* (Partial Territorial Plans) for each of Catalonia's supraregions (*vegueries*). However, approval of the *Pla Territorial General de Catalunya* was delayed for 12 years. In this regard, Marshall (1995) notes that one of the elements that might have hampered its approval process was the unresolved debate about the administrative-division alternative to the provincial level. As Oliveras (2009) states, although there had been a collective demand for replacing the provincial division since 1976, there were also important divergences among the supporters of such changes. On the one hand, there was an option to promote the *comarques* as the unique administrative level between the national (Catalonia) and the local (municipalities) levels. On the other hand, there was an alternative based on implementing another administrative level—i.e., the *vegueries*—between the national and the *comarca* levels. Thus, there was a discussion about the fact that the former option conceptualized the Catalan territory as a homogenous territory (each *comarca* or region would allocate the same urban facilities, services, etc.), whereas the latter option recognized Catalonia as a heterogeneous urban reality in which the role played by some urban areas (e.g., the capital of each *vegueria* or supraregion allocating the high-order urban functions) was more important than the role played by other urban areas (e.g., the capital of each *comarca* or the remainder of the cities within each *vegueria*). This debate seemed to be resolved in 1987, when the Catalan Parliament approved a regulation dividing Catalonia into 41 *comarques* (regions) and leaving open the possibility of the creation of functional supraregions (*vegueries*) in accordance with the *Pla Territorial General de Catalunya*.

Since the 1995 approval of the *Pla Territorial General de Catalunya*, development of each Partial Territorial Plan has begun. Nevertheless, like before, these works went tremendously slowly. The best example of this was the case of the Partial Territorial Plan for the supraregion of Barcelona. Denominated the *Pla Territorial Metropolità de Barcelona* (Barcelona Metropolitan Territorial Plan), the first draft took three years (1998) and approval took fifteen (2010). The primary reasons for these delays might be explained as follows. There were strongly distinct political interests related to Barcelona's future role. From 1979 until 2011, the Socialist Party (PSC-PSOE) controlled Barcelona's city council, along with most of the metropolitan bodies (such as the *Mancomunitat de Municipis*) that comprised a municipal association for planning cooperation. This situation might have also hampered the elaboration process of the *Pla Territorial Metropolità de Barcelona* (which was partly dependent on the Catalan government, which was ruled by the opposition party, *Convergència I Unió*), if that plan's spatial proposal sought to define a balanced metropolitan territory using a polycentric development strategy that did not reinforce the Barcelona model. As Marshall (1996, 2000) notes, since 1988, Barcelona's city council had developed several strategic plans based on inserting Barcelona into both the network of Eurocities and metropolitan centers worldwide. This objective, which can be associated with the idea of the 1934 *Pla Macià*, is known as the Barcelona model. Its motto, as emphasized by Marshall (1996:153), is as follows: "*consolidate Barcelona as an enterprising European metropolis, with influence over its macroregion and with a modern socially balanced quality of life, deeply rooted in Mediterranean culture*".

In 2003, the problems of the slow planning process were (to some extent) solved: after an election for the Catalan Parliament, the Socialist Party formed a coalition government, ending 23 years of *Convergència I Unió* rule in Catalonia. Accordingly, Catalonia's government and Barcelona's city council had the same political tendency and territorial interests. Between 2003 and 2010, the regional planning unit within the Department of Territorial Policy and Public Works, headed by the geographer and socialist politician Oriol Nel·lo and coordinated by the architect Juli Esteban, elaborated seven Partial Territorial Plans in accordance with the 1995 *Pla Territorial General de Catalunya*. With these approved, the entire Catalan territory was finally covered with territorial plans that had administrative implications. In this regard, it is worth noting that these plans, as noted by Esteban (2003, 2006) were conceptualized according to a territorial model based on accepting and canalizing the metropolitanization process through its articulation in a polycentric network of cities that could be considered important. Interestingly, this implied the withdrawal of the Barcelona model advocated for several years from the socialist political spheres, and the implementation of the polycentric vision as the most suitable territorial development strategy for organizing the entire Catalan territory. Perhaps because of this, the 2010 approval of the *Pla Territorial Metropolità de Barcelona* was considered by the heads of this plan (see Nel·lo, 2011) as the end of the planning debate between Barcelona and Catalonia; that debate originated in the early decades of the 20th century. Before analyzing the provisional proposal of this latter plan, the content of the 1995 *Pla Territorial General de Catalunya* that provided the basis for it is considered.

The 1995 Pla Territorial General de Catalunya: revisiting the idea of Catalunya-ciutat by implementing a polycentric network of cities

The *Pla Territorial General de Catalunya* was elaborated under the supervision of the architect Genís Carbó, who was the head of the regional planning unit within the Department of Territorial Policy and Public Works. The territorial proposal of the *Pla Territorial General de Catalunya*, which is reported in Figure 3.7, proposed a polycentric structure for the entire Catalan territory that implied a significant contribution to overcome the planning debate about the territorial organization.

From my perspective, the polycentric planning vision of the *Pla Territorial General de Catalunya* can be deduced from the following core message, which can be found in its report: "*The coupling of Catalonia-Barcelona is indissoluble. Catalonia is a single functional unit because of the interactions between its territories…the economic activity of the distinct territories of Catalonia is complementary and also, it does not have a homogenous distribution but is essentially concentrated on the existing urban systems, the cities. Each territory creates its city which is its capital and each city has simultaneously its territory which is cohesive by this city*" (Generalitat de Catalunya, 1995:14) [translation by the author]. This vision is elaborated into three objectives: boosting economic development, balancing the territory to obtain similar per-capita income levels, and organizing urban growth to favor citizens' quality of life, environmental preservation and equity in terms of the location of personal services. Three planning actions were defined to fulfill these objectives. First, the *Pla Territorial General de Catalunya* developed planning strategies with respect to territorial, environmental, and economic aspects. Second, it defined a prospective population model by considering the administrative division of 41 regions (*comarques*) and 6 supraregions (*vegueries*), with the aim of defining the distribution of population and urban functions across the entire Catalan territory in accordance with the desired territorial model by 2026. Third, it developed planning guidelines to be considered in the elaboration of the subsequent sub-territorial plans (e.g., Partial Territorial Plans).

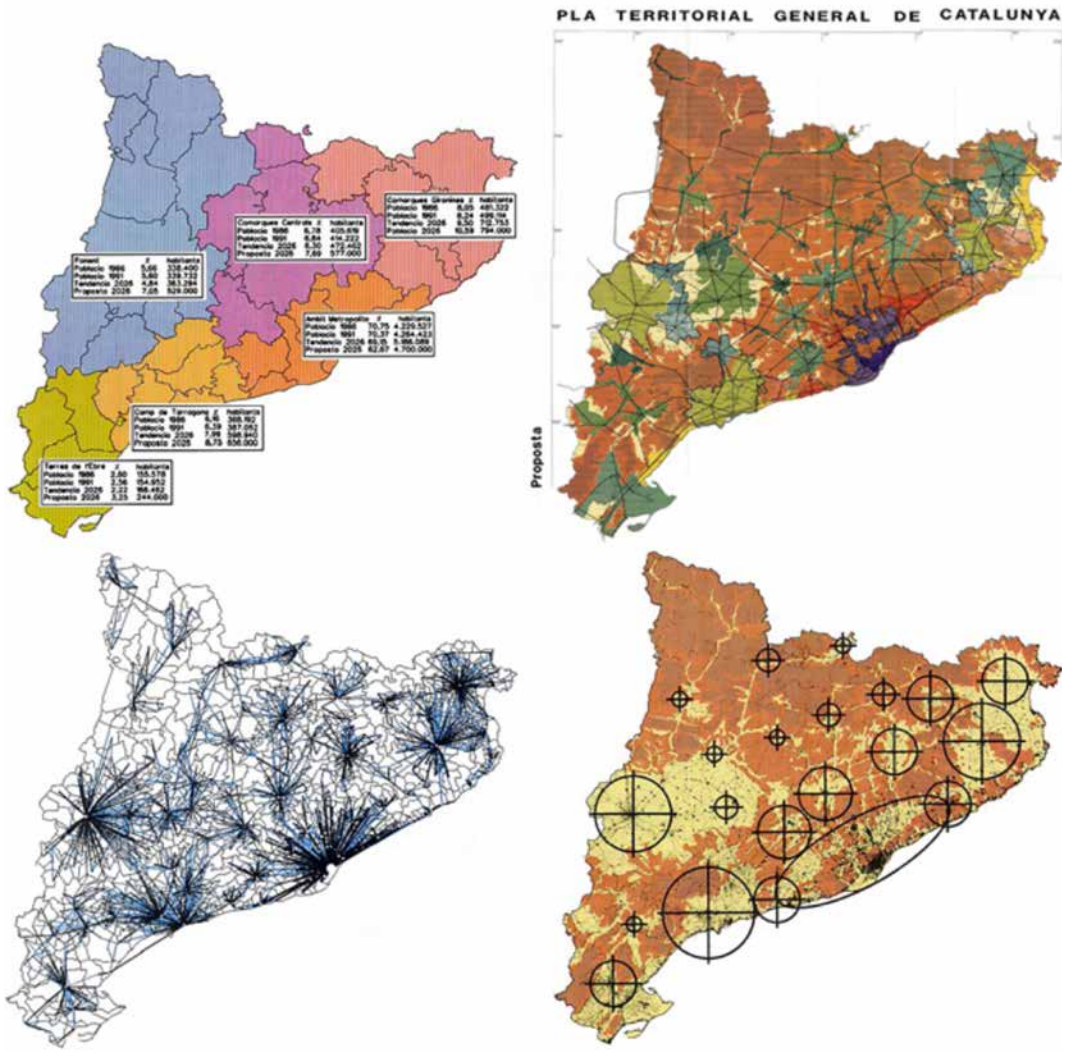


FIGURE 3.7 The 1995 *Pla Territorial General de Catalunya*

Source: Generalitat de Catalunya (1995).

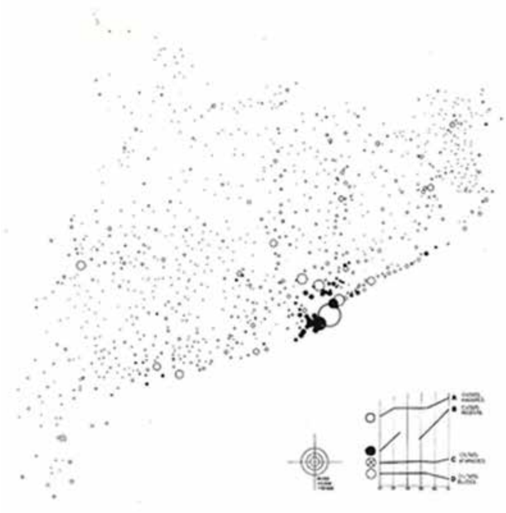
These two latter proposals determined a translation of the polycentric vision of the *Pla Territorial General de Catalunya* into a specific polycentric territorial model, in which three key aspects can be detected. First, the polycentric territorial model of the *Pla Territorial General de Catalunya* was based on achieving a more balanced population distribution (see Figure 3.7, top left). This was intended to diminish the trend of a concentrated population in the 7 regions that comprised the Barcelona metropolitan area. In this regard, the plan proposed that the population of the Barcelona metropolitan area would be 4.7 out of the region's 7.5 million inhabitants by 2026, thus implying a reduction of its share of Catalonia's total population from 71.17% in 1981 to 62.07% by 2026.

Second, in addition to decentralization, the plan proposed polycentric development within the Barcelona metropolitan area to organize growth and mitigate the congestion of the central city (see Figure 3.7, top right). This proposal was primarily based on not only reinforcing or strongly developing the urban settlements located to the north of Barcelona but also designing an axial grid pattern of transportation infrastructures to connect the urban settlements, similar to the proposal of the 1966/1974 *Pla Director de l'Àrea Metropolitana de Barcelona*. In this regard, the *Pla Territorial General de Catalunya* reinforced the role played by the cities of Sabadell, Terrassa, Sant Cugat del Vallès, Cerdanyola del Vallès and Montacada I Reixac (marked in the lightest violet in Figure 3.7, top right) and planned substantial urban development in Martorell, Granollers, Sant Celoni, Cardedeu, and Llinars del Vallès together with the cities adjacent to the coast, including Mataró, Vilanova I la Geltrú, and Sitges (marked in red).

Third, the *Pla Territorial General de Catalunya* stimulated both growth in areas beyond the Barcelona supraregion and economic interaction among them to achieve a more complementarity structure, which could increase economic competitiveness. This two-fold aim caused the *Pla Territorial General de Catalunya* to define a polycentric structure on a higher scale (see Figure 3.7, bottom left and right), which was organized as follows. First, the structure was formed by urban systems (Girona, Tarragona-Reus-Valls, and Lleida) that can not only structure their supraregion but also become alternative national centers by establishing non-hierarchical relationships among themselves. Second, the structure was defined by centers (Igualada, Manresa, Vic, Figueres, Olot, and Amposta) whose function was to act as counterweights and balance the territory, but to a lesser extent compared to either Barcelona or the previous three centers. Finally, the structure was composed of systems (Tremp, Cervera, La Seu d'Urgell, Puigcerdà, Ripoll, Berga, and Solsona) that had the ability to function as centers for their surrounding rural areas notwithstanding the fact that they had a relatively small population compared to the systems mentioned above.

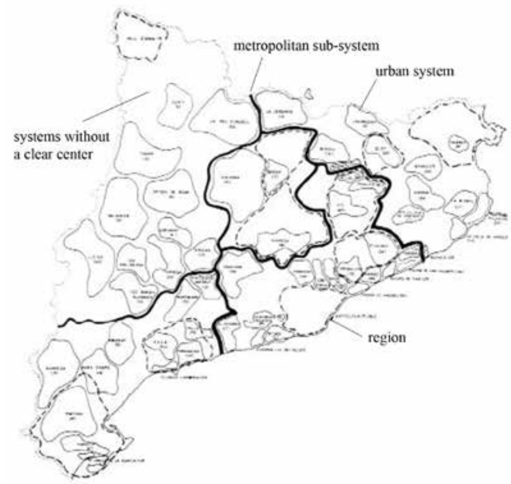
In my view, the polycentric territorial model of the *Pla Territorial General de Catalunya*, which can be briefly defined as a network of cities, could have been influenced by the avant-garde planning ideas for the Catalan territory coined by studies in the 1980s. It is important to acknowledge this relationship because the polycentric territorial ideas of these studies contributed to unfolding an understanding of Catalonia as a reality organized through a polycentric network of cities in which non-hierarchical, complementary relationships arose in parallel to the hierarchical relationships previously depicted, for example, by the 1936 *Divisió Territorial de Catalunya*. They could also have helped the *Pla Territorial General de Catalunya* propose a novel planning vision of polycentricity. Perhaps, the most important studies were those of Busquets (1981), Cassasas and Clusa (1981), Riera (1987), and Castañer (1992), whose planning concepts are reported in Figure 3.8.

Busquets (1981) proposes the idea that beyond Barcelona, there was a set of 30 Catalan cities with populations of between 10,000 and 100,000, which had enough potential to become the (joint) second capital of Catalonia through the establishment of a polycentric network of cities with more than 1 million inhabitants. Although that study does not mention the exact concept of an urban network, the concept was indirectly conceptualized by the spatial organization proposal for Catalonia. The concept of an urban network appears more explicitly in Cassasas and Clusa (1981). Through the use of residence-to-work and phone flows that study shows that the Catalan territory was functioning as a heterogeneous reality, not a set of homogenous entities such as the *comarques* (regions). This interpretation of the Catalan territory diverged from the aforementioned proposal of the 1936 *Divisió Territorial de Catalunya*, which was based on 38 central places and their functional hinterlands. This heterogeneity, as stressed by Cassasas and Clusa (1981), was composed of four territorial systems (see Figure 3.8b): urban systems composed of a set of cities with important daily resident-to-work relationships; systems without a clear center that had horizontal and non-hierarchical relationships among their constituent parts; regions (*comarques*) in which there was a prominent city (the capital) that dominated the rest of the regional territory; and metropolitan sub-systems, which were formed from the combination of the previous three territorial logics. Similarly, but through studying urban functions and the residence-to-work flows, Riera (1987) explains the polycentric reality of Catalonia by examining the urban network and hierarchies among cities derived from delimiting their commercially, administratively, and service-influenced areas, which caused her to stress the existence of fourteen centers with cities of similar size but different urban functions (see Figure 3.8c). Finally, evidence of a network system was found by Castañer (1992), who analyzes travel-to-work flows to define the network of *ciutat reals* ('real cities') or *àrees de cohesió* ('cohesion areas') formed by a grouping of municipalities that had tight, functional, non-hierarchical interdependencies and that could heterogeneously organize the entire Catalan territory (see Figure 3.8d).



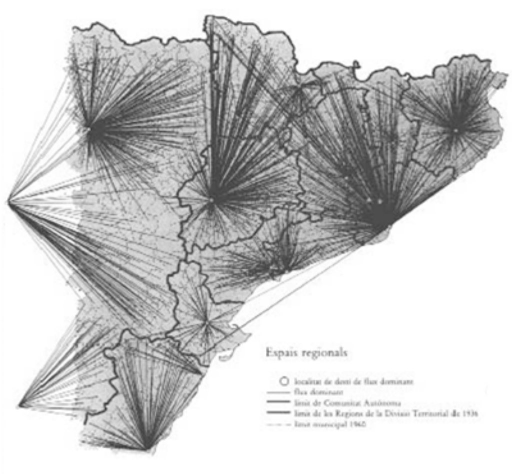
A Barcelona as a capital of Catalonia or Catalan cities?

Source: Busquets (1981).



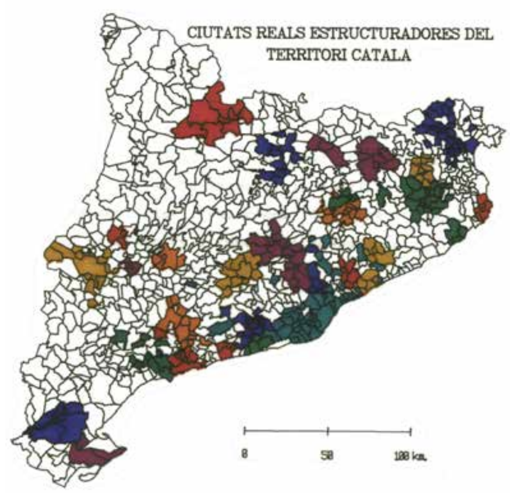
B The functional heterogeneity of Catalonia

Source: Cassasas and Clusa (1981).



C The urban network in Catalonia: regional spaces

Source: Riera (1987).



D The cohesion areas: the real cities of Catalonia

Source: Castañer (1992).

FIGURE 3.8 Contributions to defining polycentric Barcelona and Catalonia

In this regard, I think that the polycentric network of cities identified by the *Pla Territorial General de Catalunya* both within and beyond the Barcelona metropolitan area can be conceptualized as the first territorial model that could enable the induced decentralization from Barcelona and the organization of urban growth without hampering the achievement of more balanced territorial development in Catalonia. In addition, this polycentric territorial model could have contributed to revisit the old planning idea of *Catalunya-ciutat* by adding other conceptual dimensions (e.g., urban networks or the urbanization process as an opportunity to organize growth) compared to other interpretations—for instance, the aforementioned idea of the 1932 *Regional Planning* based on the *urbanization of the country* (see section 3.1). However, the *Pla Territorial General de Catalunya*'s primary contribution may have been its definition of urban Catalonia as a single polycentric reality formed of distinct cities into which Barcelona is integrated. The reason for this observation is that this novel vision of the entire territory of Catalonia as a single polycentric network of cities will replace the historical planning debate that contrasts Barcelona and Catalonia through the coming elaboration of a set of Partial Territorial Plans.

For example, the polycentric territorial model proposed by Nel·lo (2001), which was the basis for defining the urbanization model of the approved version of the *Pla Territorial Metropolità de Barcelona* in 2010, defined its point of departure in the planning vision of polycentricity coined by the 1995 *Pla Territorial General de Catalunya*. More specifically, that study proposed a territorial vision with prescriptive or normative aspects referred to as *ciutat de ciutats* (city of cities) for identifying a polycentric network of cities in Catalonia that have (or should have) the capacity to guarantee a reasonable, equitable (balanced) territory. The prescriptive aspects of this planning concept of *ciutat de ciutats* were represented by the call to examine several ongoing territorial dynamics (e.g., deconcentration or diffusion of economic activities) both to organize the territory and to prepare the future of the city according to a set of economic, social and environmental principles[9].

The 1998 Pla Territorial Metropolità de Barcelona: a provisional polycentric plan

A team headed by engineer Albert Serratosa elaborated the first proposal of the *Pla Territorial Metropolità de Barcelona*, which referred to the Partial Territorial Plan for the Barcelona's supraregion. The polycentric nature of the proposal, as Figure 3.9 indicates, was primarily based on organizing the future urban development estimated by the *Pla Territorial General de Catalunya*, following its planning objectives.

More specifically, the polycentric proposal of the 1998 *Pla Territorial Metropolità de Barcelona*, as Serratosa (2000) has noted, was based on three emblematic characteristics. The first characteristic is the compactness of the population in certain urban zones to avoid dispersion, with the objective that by 2026, only 8% of the population will live in the open spaces that represent 80% of the territory, whereas the remainder of the population (92% of 4,700,000 inhabitants) will live in compact areas. The second characteristic is the development of these compact zones, which formally defined the polycentric form, into *metropolitan city blocks* with densities between 60 and 140 inhabitants per hectare. As Figure 3.9 shows, the most dense *metropolitan city blocks* beyond Barcelona were in the cities of Sabadell, Terrassa, Sant Cugat del Vallès, Cerdanyola del Vallès, Rubí, and their surrounding second-order cities (e.g., Ripollet, Barberà del Vallès and, Montcada I Reixac, among others), along with Granollers and its adjacent second-order cities. The location of these *metropolitan city blocks* illustrates the importance that this first proposal of the *Pla Territorial Metropolità de Barcelona* gave to those centers located in the north of Barcelona to absorb the decentralized population from the central city and to organizing and canalizing other future urban developments. The third characteristic is the organization of these *metropolitan city blocks* through transport networks that follow an orthogonal grid model of transportation, as proposed by the 1966/1974 *Pla Director de l'Àrea Metropolitana de Barcelona*. The purpose of this, as Serratosa (2000:54) states, was to change the orientation of the dominant flows: "*balancing the flows following the rivers perpendicular to the sea and the parallel transit axis to the coast is one of the proposals of the Plan: a grid pattern for breaking the centralism and the radius concentric model to obtain a more homogeneous distribution of population*

9 Nel·lo (2001) states the need to develop policies that enhance the following aspects of the city: economic development, structure of the urban network, accessibility and mobility, citizens' rights, environmental quality, and governance.

and economic activities across the metropolitan area" [translation by the author]. Accordingly, this proposal was the first to apply the novel polycentric vision of the 1995 *Pla Territorial General de Catalunya*. However, it was never approved in this form, probably because of the pre-2003 political standstill mentioned above. That notwithstanding, the follow-up and approved version, which are the focus of analysis in chapter 4, preserved some of the *Pla Territorial General de Catalunya*'s main ideas.

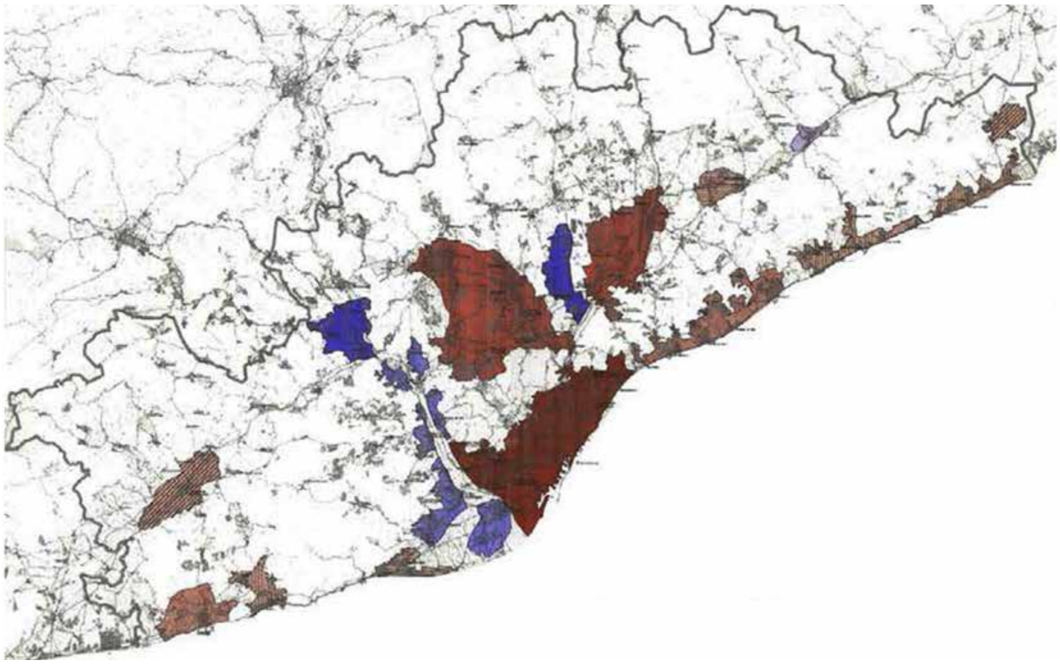


FIGURE 3.9 The 1998 *Pla Territorial Metropolità de Barcelona*: a provisional proposal

Source: Generalitat de Catalunya (1998, 2010).

§ 3.5 Conclusion and discussion

This study of the planning proposals for Barcelona and Catalonia and the territorial model that they advocated has illustrated the origin of the polycentric vision in Catalonia's planning practice. It has also shown how in successive spatial plans, the vision itself changed over time in terms of its concepts and elaboration in actual strategies. Moreover, this study provides valuable lessons about how the makers of spatial plans in Catalonia address polycentric development and thus, how the understanding of polycentric development in planning could be linked to the ongoing academic debate on polycentricity in research. Four main conclusions can be drawn from this longitudinal study on the understanding of polycentricity in planning.

First, the origin of a planning vision of polycentricity as a development strategy in Catalonia is rooted in the early 1930s, when the remarkable distrust of the city's industrialization by strong social, cultural, and political movements was translated into two distinct planning proposals aimed at addressing the increasing concentration of people and economic activities in the capital city of Barcelona. Whereas polycentric development was understood in the 1932 *Regional Planning* as a development strategy aimed at limiting Barcelona's growth through the decentralization of economic activities and population, the 1936 *Divisió Territorial de Catalunya* advocated for a set of central places across Catalonia's entire territory to limit the negative consequences of rapid urbanization caused by industrialization. However, both of these planning proposals contributed to defining the basis for the subsequent planning debate in Catalonia. The debate centered on not only the urban-rural opposition between Barcelona and Catalonia but also where the makers of the plans perceived polycentric development as the most suitable development strategy to overcome that antagonism.

Second, the understanding of polycentric development in planning gained a quantitative nature and experienced a relevant transformation during the dictatorship (1939-1976). During this period, the makers of the plans in Catalonia paid increasing attention to the urbanization pattern and how it evolved through in-depth studies of the demands for urban development while their planning proposals were becoming less connected to any social, cultural, and political movements. For instance, all spatial plans between 1939 and 1976 carried out demographic analyses to predict cities' future populations and how they would affect the polycentric structure. The shift in the conceptualization of polycentric development in planning occurred between the 1950s and the early 1960s, when the impact of urbanization trends and a set of liberal and austere economic policies (e.g., the 1959 *Plan Estabilización*) revealed that the goal of limiting Barcelona's city size resulted in an arduous assignment that required constant revisions of spatial plans. In particular, the planning vision of polycentricity changed from one that was only conceptualized as a decentralization strategy aimed at restricting Barcelona' growth to one that was also perceived as a suitable territorial model that could organize and canalize future urban development building on the urban dynamics themselves. This novel polycentric development vision became clear in the territorial model of the *1966/1974 Pla Director de l'Àrea Metropolitana de Barcelona*. In marked contrast with two preceding plans (the 1953 *Pla Comarcal d'Ordenació Urbana de Barcelona* and the 1959 *Pla General d'Ordenació de la Província de Barcelona*), this plan used estimated urban growth to define a polycentric territorial model based on both creating new centers and strengthening existing centers to absorb future urban growth. Moreover, this growth should take place in a territory larger than previously identified, crossing administrative borders and more closely resembling Barcelona's real metropolitan area.

Third, the antagonism between Barcelona (city) and Catalonia (countryside) was definitively overcome when several academic studies that appeared after 1976 and the spatial plans of the 1995 *Pla Territorial General de Catalunya* and the 1998 *Pla Territorial Metropolità de Barcelona* (provisional proposal) began to define the entire territory of Catalonia, including the capital city of Barcelona, as a single polycentric reality in which important functional interdependencies and complex hierarchies existed. The point was that the makers of these plans added the network system paradigm to the conceptualization of polycentric development in planning at the turn of the 1960s, which allowed them to identify a polycentric network of cities both within and beyond the Barcelona metropolitan area. Therefore, this polycentric network of cities was the first polycentric territorial model that could enable both the decentralization from Barcelona and the organization of urban growth without hampering the achievement of more balanced territorial development in Catalonia.

Fourth, although the makers of the spatial plans in Catalonia/Barcelona have coined distinct conceptualizations of polycentric development over time, what they have in common is that they do not use an empirical framework to identify the polycentric territorial model of the spatial plan and to test whether such a territorial model could achieve its economic, social, and environmental objectives. More specifically, the makers of the plans in Catalonia have traditionally developed a polycentric territorial model by diagnosing the ongoing urbanization trends (e.g., concentration of population, deconcentration of economic activities, etc.) and deriving the consequences of those trends (e.g., congestion, quality of life, environmental preservation, etc.), followed by morphologically identifying a set of cities (or urban areas) in which future urban development should take place, which was assumed to achieve the plan's objectives. In practice, this has generally translated into different prescriptive or normative approaches to define a polycentric development strategy. Whereas the 1959 *Pla Provincial de Barcelona* bet on a polycentric territorial model developed by establishing a concentric model of transport infrastructures for linking its multiple centers, the 1966/1974 *Pla Director de l'Àrea Metropolitana de Barcelona*, for example, established a tangential model of transport infrastructures based on its belief that in this manner, congestion effects would be mitigated and therefore, better metropolitan performance will be achieved.

Implications for the academic debate about polycentricity

In this context, I think that it is possible to discuss a distinct understanding of polycentric development in planning, one that could be more closely connected to the ongoing academic debate on polycentricity in research. The study on how the makers of Catalonia's spatial plans have addressed polycentric development revealed that such development has only been conceptualized using prescriptive or normative aspects. It could be then argued that regardless of whether Catalonia's spatial plans are based on poor empirical evidence, planning policies could not be adequately feasible and effective. That result would call for the need for an understanding of polycentric development that aims for greater integration of informed knowledge stemming from the concept of polycentricity in research and its related economic, social, and environmental effects into the elaboration of spatial plans aimed at grounding policies on empirical evidence. An important milestone of this more evidence-informed understanding of polycentric development would be, for example, bringing the city's performance (i.e., the estimated effects of the link between polycentricity and performance) to architects, planners and policymakers in an usable form (e.g., elasticities and average marginal effects). This could provide planners and policymakers with useful information that would facilitate a more appropriate spatial organization of the territory according to certain economic, social, and environmental planning objectives.

Of course, this understanding of polycentric development does not argue that evidence should be the only influence on policy, given that spatial plans are politicized and other factors such as ideology and interests also play important roles (see, e.g., Davoudi, 2006; Faludi and Waterhout, 2006; Weiss, 2001). Indeed, the close examination of how polycentric development is understood in Catalonia's planning practice over time has provided valuable lessons about the extent to which factors that go beyond evidence are significant to the definition of a territorial model. For example, the strong political, social, and cultural concerns over and interests in avoiding industrialization (the 'gigantism' of Barcelona) led both to the rise of a polycentric vision for Catalonia during the first third of the 20th century and to the strenuous objection to a monocentric alternative since that time. Indeed, it can be said that the 1934 *Pla Macià or Nova Barcelona* has become a unique call for planning a monocentric Catalonia to advance Barcelona as a national and international capital. Another example was the lack of political support for approving the 1966 *Pla Director de l'Àrea Metropolitana* because it delimited a metropolitan territory for Barcelona (approximately 3,000 square kilometers) that far overflows the legal-administrative borders that this spatial plan should have formally considered (the region of Barcelona defined by the 1953 *Pla Comarcal*, which comprised 485 square km), thus considering a part of the territory to fall within the jurisdiction of the Province of Barcelona.

Before entering the part of the thesis that aims to conduct research on the conceptualization of polycentricity, the empirical analysis of the dis(advantages) that come with polycentricity, and how its benefits can be realized in planning practice, I will first discuss the approved version of the *Pla Territorial Metropolità de Barcelona* (Barcelona Metropolitan Territorial Plan) in chapter 4.

4 The 2010 Barcelona Metropolitan Territorial Plan: the end of the debate?

§ 4.1 Introduction

The previous chapter concludes that although the planning debate initially centered on the urban-rural opposition between Barcelona and Catalonia, that opposition was replaced by a polycentric vision of the territory since the 1976 establishment of democracy. The *Pla Territorial General de Catalunya*, approved in 1995, presents polycentricity as a bridging concept that allows the urban-rural opposition to be overcome through defining Catalonia as a single polycentric urban system with important functional interdependencies. The concept was an instrument to organize urban development throughout Catalonia. The plan inspired the development of the territorial model proposed by Nel·lo (2001) that is known as *ciutat de ciutats* (city of cities). Nel·lo (2001) describes the Catalan territory as a polycentric network of cities that has (or should have) the capacity to plan its territory and prepare its future according to economic, social and environmental objectives for guaranteeing citizens' equality. This vision provided also the basis for the further elaboration of the *Pla Territorial Metropolità de Barcelona* (Barcelona Metropolitan Territorial Plan) that was approved in 2010. That plan's authors considered this approval to conclude the planning debate in Catalonia (Esteban 2012; Nel·lo 2011, 2012) for two main reasons. First, the plan contributed to an administrative definition of a metropolitan territory for Barcelona, articulated as a polycentric network of cities and including all of the cities that should be considered important to organize and canalize future urban development. Second, the plan's authors' claimed that this polycentric vision led to the most optimal spatial organization for achieving the planning objectives of economic efficiency, social cohesion and environmental sustainability.

Of course, one could question whether a planning debate can ever end because new developments and dynamics will always raise new issues and challenges. The aim of this chapter is to scrutinize the 2010 Barcelona Metropolitan Territorial Plan to contribute arguments that complement the discussion about whether a polycentric model is preferable to alternative territorial models. To do so, two lines of analysis have been considered. The first line of analysis centers on examining the Barcelona Metropolitan Territorial Plan's planning objectives, scenarios, models for territorial development (alternatives and the preferred model), and planning proposals, along with public reactions to the plan. The second line of analysis focuses on whether there are clear discrepancies between the polycentric network of cities proposed by the Barcelona Metropolitan Territorial Plan and developments on the ground; in other words, it tests the capacity of the Barcelona Metropolitan Territorial Plan's polycentric model to properly organize and canalize urban development. Therefore, this chapter answers the specific research question (see section 2.5 in chapter 2) of the extent to which the polycentric model is preferred over alternative territorial models of development models in the most recent spatial plan for the Barcelona metropolitan region. In addition, it examines the extent to which a polycentric development vision corresponds to actual development.

Answering this specific research question also provides useful information about how polycentric development could be interpreted in planning, borrowing from the understanding of polycentric development in the current debate on polycentricity in research (see Figure 1.3 in the introduction to this thesis). For example, it could reveal that some shortcomings in the application of a polycentric development strategy in spatial plans stem from the lack of a more evidence-informed planning based on an improved knowledge of polycentricity, primarily with respect to its conceptualization (identification and measurement) and effects on the economic, social, and environmental performance of metropolitan areas.

The rest of this chapter is organized as follows. The first line of analysis is presented in section 4.2. The second line of analysis is presented in section 4.3, in which I explore whether demographic trends between 1981 and 2012 correspond with the planning vision of polycentricity proposed by the 2010 Barcelona Metropolitan Territorial Plan. Finally, section 4.4 discusses whether my analyses support both the proposition that the Barcelona Metropolitan Territorial Plan concludes the long-running planning debate in Catalonia and the call for a more evidence-informed planning.

§ 4.2 The 2010 Barcelona Metropolitan Territorial Plan

The regional planning unit within the Department of Territorial Policy and Public Works of the Catalan Government elaborated the Barcelona Metropolitan Territorial Plan. The geographer Oriol Nel·lo, in coordination with the architect Juli Esteban, led the process of the plan's elaboration. The delimitation of the Barcelona metropolitan region corresponds to the territory that had been delimited by the *Pla Director de l'Àrea Metropolitana de Barcelona* (Director Scheme of the Barcelona Metropolitan Area) back in 1966. The area comprises seven regions (*comarques*): Alt Penedès, el Baix Llobregat, el Barcelonès, el Garraf, el Maresme, el Vallès Occidental and el Vallès Oriental. These regions contain 164 municipalities. With more than 65 percent of Catalonia's population (5 out of 7.5 million) in 2012, the Barcelona Metropolitan Region is Catalonia's main agglomeration.

The elaboration of the Barcelona Metropolitan Territorial Plan—i.e., the *Pla Territorial Parcial* (Partial Territorial Plan) for the *vegueria* (supraregion) of Barcelona, as explained in chapter 3—has been implemented in accordance with regulation 23/1983 of *Política Territorial* (Territorial Policy), which defines the legal framework to develop regional and supraregional planning in Catalonia. This regulation established that the planning territory of Partial Territorial Plans could cover either one *comarca* (region) or a group of adjacent *comarques*, which are referred to as *vegueries* (supraregions). In 1995, the *Pla Territorial General the Catalunya* identified six *vegueries* (supraregions) for which Partial Territorial Plans should be elaborated.

As noted above, the planning territory for the *vegueria* of the Barcelona metropolitan region resembles the territorial delimitation proposed by the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona*, ratified by regulation 7/1987, which aimed to establish planning actions in both the agglomeration of Barcelona and those regions within its area of influence. The rules state that Partial Territorial Plans are required to develop the planning instruments needed to allocate the *Pla Territorial General de Catalunya*'s forecasted population growth, housing, and land demand for industrial services and personal services. Additionally, they must elaborate the development strategies and objectives of the *Pla Territorial General de Catalunya*, which include strengthening the polycentric structure and diminishing territorial disparities (DOGC, 1995). This normative framework conditioned the operational model of the 2010 Barcelona Metropolitan Territorial Plan, which is described in detail in Figure 4.1.

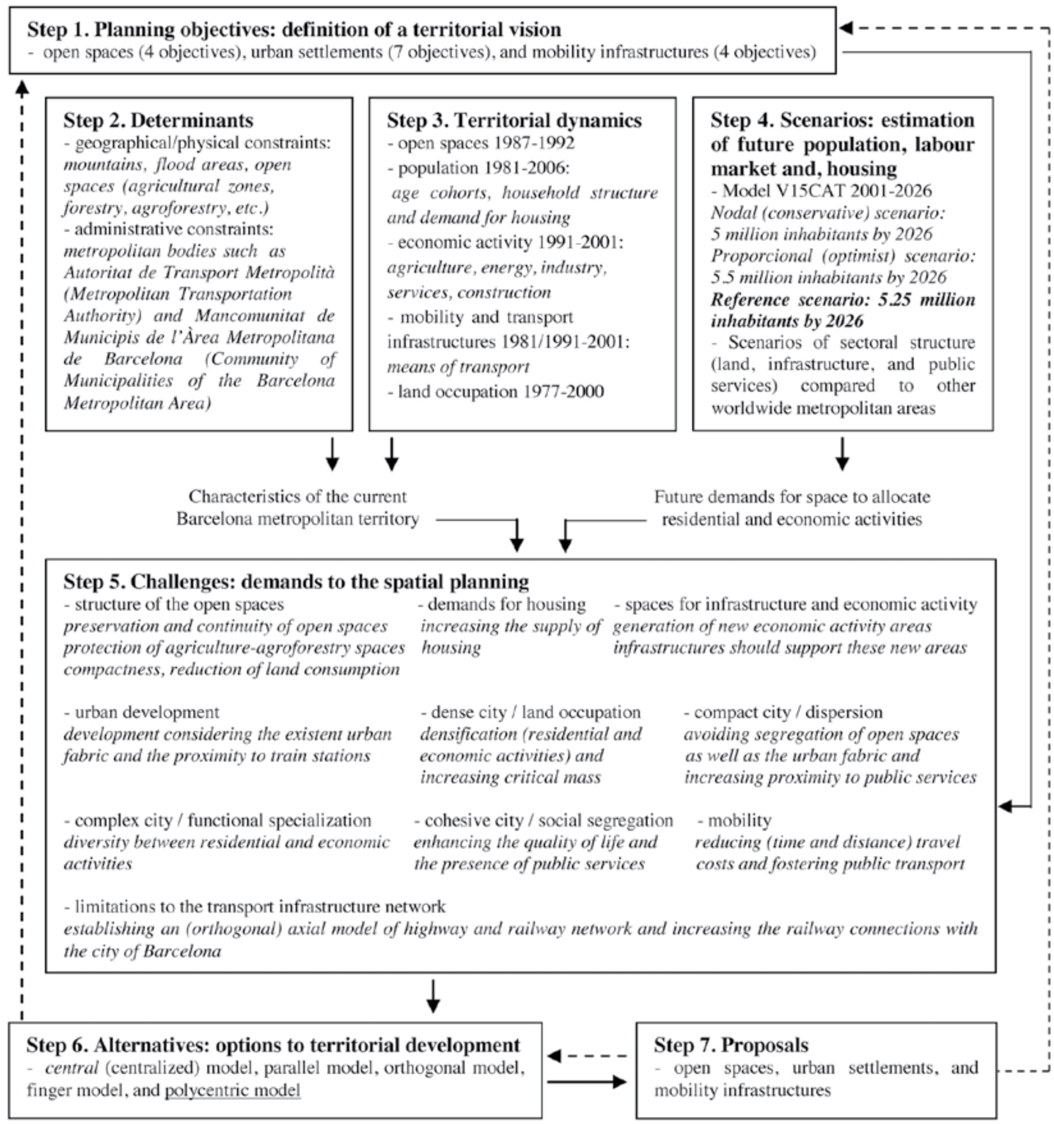


FIGURE 4.1 How the 2010 *Pla Territorial Metropolità de Barcelona* (Barcelona Metropolitan Territorial Plan) developed

In step one of the development of the Barcelona Metropolitan Territorial Plan, sets of objectives are defined that jointly determine the territorial vision. In step two, the physical characteristics of the territory of the Barcelona metropolitan region are described; in step three, the territorial dynamics are described. The fourth step centers on forecasting development scenarios for the Barcelona metropolitan region until 2026, which leads to an assessment of the quantity of land needed to allocate future residential and economic activities. This assessment, together with the insights gained in steps two and three into territorial characteristics and dynamics, determines the challenges to which the spatial plan should respond. These responses should contribute to correct inefficient situations (e.g., the fragmentation of open spaces), consider current demands on the territory (e.g., spaces for infrastructures and economic activity) and guarantee the future competitiveness, cohesion and sustainability of the Barcelona metropolitan region. The 2010 Barcelona Metropolitan Territorial Plan then elaborates alternative options for territorial development (step 6) and their related planning proposals (step 7) that correspond to planning objectives. These steps are explained in detail below, focusing on the proposed territorial model and planning vision of polycentricity.

Planning objectives of the Barcelona Metropolitan Territorial Plan

The Barcelona Metropolitan Territorial Plan aims to define a territorial vision that organizes the territory of the Barcelona metropolitan region to become more economically efficient, socially equitable and environmentally sustainable (Generalitat de Catalunya, 2010). To do so, it considers both the opportunities and risks arising out of the urbanization process and develops a set of fifteen general planning objectives related to three main aspects: open spaces (agricultural, forestry and natural zones), urban settlements (cities, towns, urbanization and industrial zones) and mobility infrastructures (highways networks, railroad networks, logistic areas, ports and airports). These general planning objectives, which are summarized in Figure 4.2, provide the framework for the elaboration and selection of alternative models for future development.

Planning objectives of the 2010 *Pla Territorial Metropolità de Barcelona* (Barcelona Metropolitan Territorial Plan)

Open spaces:

1. Encouraging the diversity of the territory and maintaining the quality of the biophysics matrix by extending the protected areas and improving their interconnectivity.
2. Protecting the natural, agricultural and non-urban development spaces as components of the territorial organization.
3. Preserving the landscape as a social and economic asset of the territory.
4. Moderating land consumption to increase the efficiency of the territory, reducing the costs of services and facilitating the development of public transportation.

Urban settlements:

5. Favoring the social cohesion of the territory and preventing the spatial segregation of urban areas. In this regard, spatial planning should favor a truly territorial balance based on guaranteeing similar per capita income levels and accessibility levels with respect to basic facilities and personal services independent of a person's place of residence.
6. Protecting and enhancing urban heritage with particular interest in large and medium-sized cities as a mechanism to reduce the promotion of new urban developments.
7. Providing an effective housing policy by considering future urban development focused on cities that have important services and public transportation.
8. Facilitating the co-existence of economic and residential activities in urban areas and streamlining the implementation of industrial or services areas that are functionally autonomous from the urban areas.
9. Mitigating the effects attributable to the demand for second homes.
10. Ensuring compactness and continuous growth based on the fact that spatial planning should establish clear guidelines to guarantee that urban developments are logically contiguous with existing urban areas, along with the achievement of densities that facilitate the reasonable use of urbanized land.
11. Strengthening the territory's nodal structure through urban growth focused on cities of a certain importance, i.e., provincial or regional capitals, as a method of consolidating the polycentric metropolitan region.

Mobility infrastructures:

12. Making mobility a right, not a duty for citizens; the primary objectives are to increase accessibility and decrease trip distances and times.
13. Providing a greater concentration of public transportation by promoting the nodal structure and compactness of the urban settlements system.
14. Paying particular attention to roads that structure the urban development and organize Barcelona's entire metropolitan territory to improve the roadways.
15. Integrating the Barcelona metropolitan region into the network system of mobility and transport (particularly with respect to airports and high-speed rail) on a European scale.

*These planning objectives are based on the political, social and technical framework previously defined by the National Agreement for the Infrastructures in Catalonia (Generalitat de Catalunya, 2009a) and the Director Plan for Transport Infrastructures (ATM, 2009).

FIGURE 4.2 Planning objectives of the 2010 Barcelona Metropolitan Territorial Plan

Source: own elaboration based on Generalitat de Catalunya (2010).

To a large extent, the general planning objectives proposed by the Barcelona Metropolitan Territorial Plan are nothing new: for the most part, they were included in earlier plans, such as the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona* and the overarching 1995 *Pla Territorial General de Catalunya*. These plans proposed a polycentric development model; moreover, several of these general planning objectives are directly associated with that model, especially objectives 4, 5, 10, 12 and 13, which emphasize the need to limit land consumption and foster social cohesion by, e.g., providing equal access to efficient public transportation.

Scenarios: estimation of future population, the labor market and housing

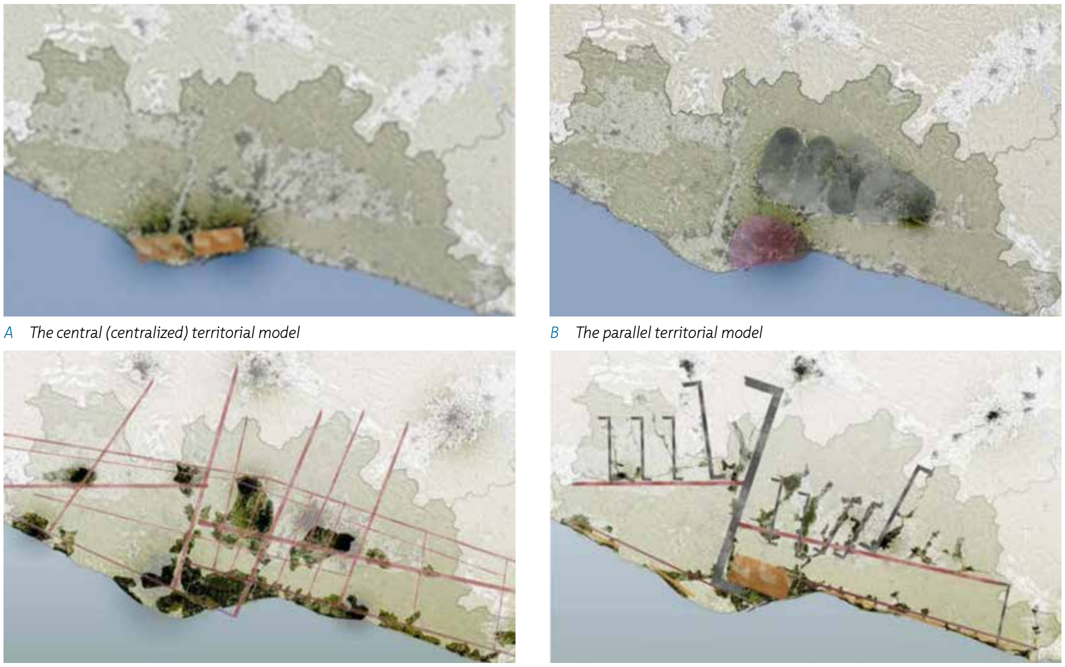
As part of the process of developing the Barcelona Metropolitan Territorial Plan, developments in population, housing demand and the labor market (jobs) were predicted through 2026 (see Generalitat de Catalunya, 2010:89-104 for a detailed explanation of its prospective model). Based on these forecasts, future demand for land to accommodate residential, industrial, service, logistic (infrastructure), and other personal-service activities was determined. Several scenarios were developed based on various sets of assumptions affecting future growth. A reference scenario was chosen that is positioned between a conservative and an optimistic scenario. The underlying assumptions of this scenario are as follows: a) moderate annual job growth in the range of 0.95% through 2011 and 0.76% from 2011-2026; b) the need to limit the growth of the construction sector and reduce its weight in the regional economy by 2026; and c) important growth of the regional economy's service sector (expected to comprise 73.3% of the Barcelona metropolitan region's jobs in 2026) while the industrial sector shrinks. This scenario would imply that by 2026, the Barcelona metropolitan region's economy would have a sectoral structure similar to those of, for instance, Milan and Birmingham, which are particularly strong in both the industry and service sectors. According to this reference scenario, the Barcelona metropolitan region's population is expected to reach 5,250,000 inhabitants and 2,541,000 jobs by 2026, an absolute growth of approximately 750,000 inhabitants and 476,000 jobs since 2001. This will require the addition of 487,500 new homes on more than 10,000 hectares of land, whereas industry and infrastructure will consume 3,200 additional hectares.

The Barcelona Metropolitan Territorial Plan does not provide a blueprint where these future demands should be spatially accommodated; instead, it identifies 15 distinct territorial subareas[10] in the Barcelona metropolitan region that together include all 164 municipalities. The municipal administrations in the same territorial subarea, each of them with important competences such as the elaboration of the municipal zoning (land-use) plan referred to as the *Pla d'Ordenació Urbanística Municipal*, must jointly determine future urban land development and allocate the forecasted growth of population, jobs, and housing according to the estimations of the Barcelona Metropolitan Territorial Plan. In doing so, those administrations' decisions should reflect the territorial model chosen in the Barcelona Metropolitan Territorial Plan and its general planning objectives with respect to open spaces, urban settlements, and mobility infrastructures.

10 These subareas are denominated as follows: Área metropolitana, which includes the municipalities (38) that form the metropolitan body headed by the central city of Barcelona and are referred to as the *Mancomunitat de Municipis de l'Àrea Metropolitana de Barcelona*, *Alt Maresme* (6 municipalities), *Arenys* (6 municipalities), *Baix Maresme* (8 municipalities), *Garraf* (6 municipalities), *Granollers-Congost* (13 municipalities), *Martorell* (7 municipalities), *Mataró* (8 municipalities), *Mediona-Anoia* (9 municipalities), *Montseny* (14 municipalities), *Riera de Caldes* (11 municipalities), *Sabadell* (5 municipalities), *Tenes-Besòs* (9 municipalities), *Terrassa* (7 municipalities), and *Vilafranca* (17 municipalities).

Alternative models for territorial development: the initial proposals

The Barcelona Metropolitan Territorial Plan identifies four initial alternative models for territorial development with their advantages and disadvantages. These are based on the question of the extent to which they not only satisfy the economic, social and environmental planning objectives but also respond to challenges related to the population, labor market and housing prospects. Figure 4.3 presents these models.



A The central (centralized) territorial model

B The parallel territorial model

C The orthogonal territorial model

D The finger territorial model

FIGURE 4.3 Alternative models for territorial development: the initial proposals

Source: Generalitat de Catalunya (2010).

One essential aspect of the first model is that it further concentrates population, economic activity and housing in the capital city of Barcelona relative to the rest of the Barcelona metropolitan region and Catalonia (model A in Figure 4.3). Thus, only Barcelona and its adjacent urban zones experience urban growth, leading to a strongly monocentric metropolitan territory. At first glance, this territorial model, which is labeled *central* (centralized) by the Barcelona Metropolitan Territorial Plan, has important advantages. First, it closely corresponds with the aforementioned general planning principle of achieving compact, dense urban development. Second, because this compact, dense new urban development is localized in (or remarkably close to) the central city, it would allow the design of an efficient public transportation network that could minimize the commuting distances traveled by a large segment of the population. Simultaneously, this type of development presents several disadvantages that are difficult to resolve. It would occupy a space that has important environmental value, an outcome that is contrary to the planning tradition (see chapter 3) of preserving the natural spaces of the Delta of Llobregat. In addition, the forecasted economic activities and residential uses would conflict with two infrastructures that are vital to the Barcelona metropolitan region and the entire Catalan territory: the El Prat airport and the Barcelona seaport. Finally, the inclusion of a high concentration of population and economic activities either in or directly adjacent to Barcelona could hamper accessibility. These activities would occupy an area that is conditioned by the current transport infrastructure network, which follows natural geographical routes such as the Llobregat River. This natural route is already occupied by several road infrastructures and it cannot absorb the new transportation networks that would be required to serve a higher population and volume of economic activity.

To address the aforementioned disadvantages of the *central* model, the Barcelona Metropolitan Territorial Plan considers three alternatives: *parallel*, *orthogonal* and *finger* (see Figure 4.3). The *parallel* alternative is based on concentrating the forecasted urban development on the north of the Collserola Mountains. In this way, an important urban area would be created parallel to Barcelona's actual conurbation, occupying the main cities of Sabadell and Terrassa and their surrounding open spaces. This territorial model is rooted in the proposal of the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona*. In that plan, the optimistic predictions that the Barcelona metropolitan region would have 6,500,000 inhabitants in 2010 and that there would be a need to diminish the accompanying congestion led to a focus on the regions of Vallès (i.e., Vallès Occidental and Vallès Oriental) as the main recipients of such growth. The development strategy was to reinforce the existing cities of Sabadell, Terrassa and Granollers or even to create new ones (e.g., Sant Cugat del Vallès, Cerdanyola del Vallès) along the B-30 highway or the corridor between Sabadell and Terrassa (see a detailed description of this plan in chapter 3). The primary advantage of this model is its compactness and densification, opportunities for efficient public transportation and its prevention of the aforementioned problems of accessibility that arise from the *central* model. However, the *parallel* development strategy leads to an important negative environmental issue in that its application entails an almost complete urban occupation of the *planes del Vallès* (Vallès plains), resulting in a loss of open spaces that not only have high environmental value but also interconnect green areas.

Compared to the *parallel* model, the alternative of the *orthogonal* territorial model can mitigate the environmental issues created by the two previous models. This model is the preferred option of the *Pla Territorial Metropolit*à (provisional proposal) in 1998. It is strongly based on linking urban development with existing mobility infrastructures. Consequently, this territorial model can guarantee citizens relatively homogenous accessibility through placing new urban development in locations with the most favorable infrastructural conditions. Despite this advantage, this territorial model has two disadvantages that can counterbalance its accessibility benefits. First, the model hampers the concentration of economic activities and housing in certain urban nodes, instead leading to a dispersed urban development that creates low densities. Second, the imposition of a mobility infrastructure network in which new urban developments will be organized may make it more difficult to design a strong network of public means of transport, which may result in higher levels of car dependency.

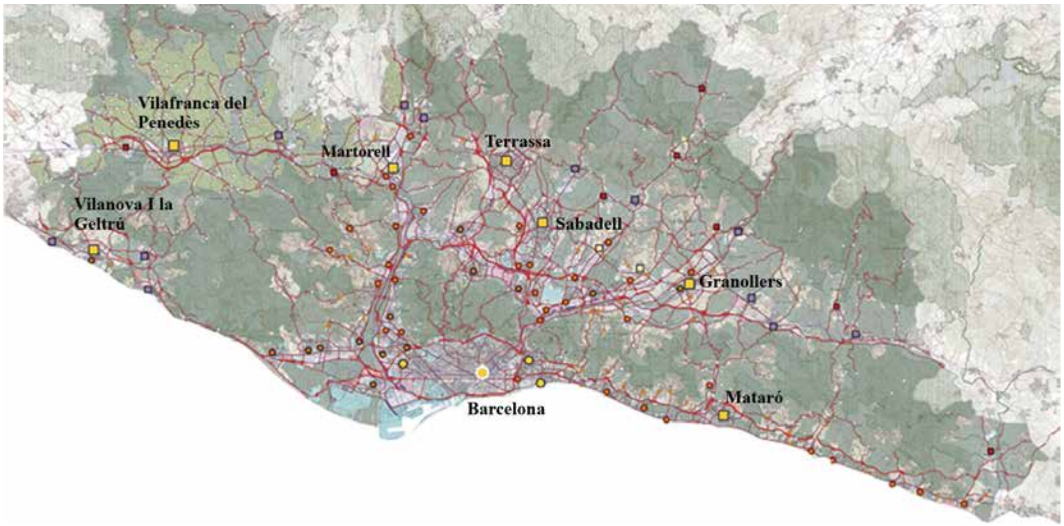
The fourth and final territorial model considered is the *finger* model. Inspiration for this model comes from the famous 1947 Finger Plan, which provided a spatial strategy for developing the Copenhagen metropolitan area. The *finger* model extends urban development beyond the central city of Barcelona into corridors leading to one or more other main urban areas. The primary difference between this development strategy and the alternatives is that in this strategy, urban development is organized following natural geographical corridors (e.g., coasts and rivers). Consequently, each of these natural corridors becomes a finger of the future urban system. This finger-mode development of urban areas has important advantages. For example, it facilitates the design of an efficient network of infrastructures (particularly railways) attributable to the linear structure of the urban settlement. Furthermore, it can reduce the pressure on open spaces because it focuses in part on existing infrastructure corridors and in part on existing urban areas. However, the *finger* model has an important disadvantage related to the fact that as its radial structure hampers the relationship between each of the corridors, instead primarily facilitating relationships with the central city of Barcelona. This structure may considerably reduce the accessibility of the most peripheral areas in each of the fingers, leading to important increases in commuting distances, and it may become difficult to preserve the open spaces between the fingers.

The preferred model for territorial development: the polycentric proposal

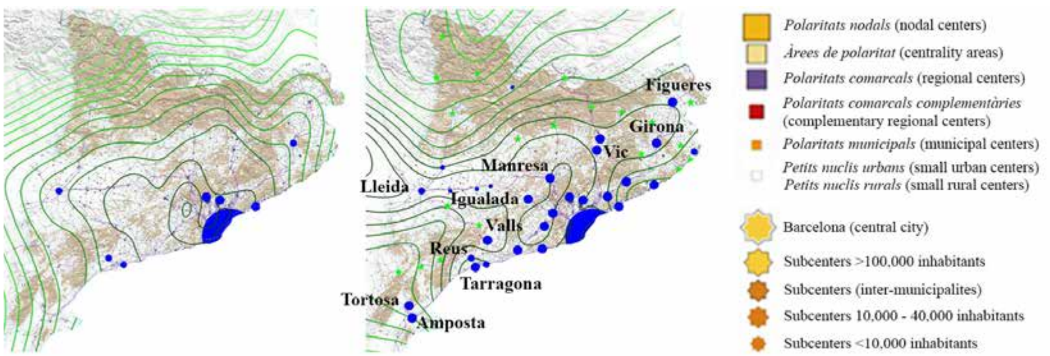
The Barcelona Metropolitan Territorial Plan proposes a territorial model based on a polycentric network of cities to overcome all of the shortcomings noted in the previous territorial models. Its basic idea is to take advantage of current major centers within the Barcelona metropolitan region and to strengthen minor cities by concentrating future urban developments in them. In this way, the Barcelona Metropolitan Territorial Plan's proposed territorial option involves neither dispersion nor excessive centralization in Barcelona. Instead, it offers a third option: the reinforcement of a polycentric metropolis articulated from both the central city of Barcelona and a set of main centers located beyond the central agglomeration. This set of centers, which are referred to as the cities of the *Arc Metropolità* (Metropolitan Arch), includes the cities of Mataró, Granollers, Sabadell, Terrassa, Martorell, Vilafranca del Penedès, and Vilanova I la Geltrú (see Figure 4.4).

More specifically, the Barcelona Metropolitan Territorial Plan (Generalitat de Catalunya, 2010:153-163) first proposes six groups of cities and then identifies and fosters their specific roles (see Figure 4.4a) to define its polycentric proposal. First, the plan identifies the *centralitats principals* (main centralities), which include the central city of Barcelona and the major urban centers (more than 100,000 inhabitants) located within its urban continuum (Badalona, Santa Coloma de Gramanet, and L'Hospitalet de Llobregat). Second, the plan proposes a set of *polaritats nodals* (nodal centers) configured using the aforementioned cities of the *Arc Metropolità* and two minor urban areas (Riera de Caldes and Tenes). Together with the city of Barcelona, these centers form the main polycentric structure. According to the Barcelona Metropolitan Territorial Plan, these centers can be divided into centers whose role is to strengthen their centrality and area of influence (Terrassa, Sabadell and Mataró) and centers whose role is to act as new areas of centrality (Martorell, Granollers, Vilafranca del Penedès, Vilanova I la Geltrú, Riera de Caldes, and Tenes). Third, the plan detects several *polaritats comarcals* (regional centers) located beyond the *urban continuums* (contiguous built-up areas between cities) of other cities. Their role is to organize surrounding areas that are primarily either rural or highly residential in nature. Fourth, the plan defines a group of cities referred to as *polaritats comarcals complementàries* (complementary regional centers), which are smaller than the regional centers (having between 10,000-40,000 inhabitants) but that have characteristics and functions similar to those centers. Fifth, the plan morphologically identifies a group of *polaritats municipals* (municipal centers), which dominate nearby smaller places and/or highly specialized residential areas notwithstanding the fact that they have a population of fewer than 10,000 inhabitants. Sixth, the plan finally recognizes a set of *petits nuclis urbans* (small urban centers) and *petits nuclis rurals* (small rural centers), which are small towns with a compact urban morphology and smaller villages with a high degree of urban-fabric discontinuity, respectively.

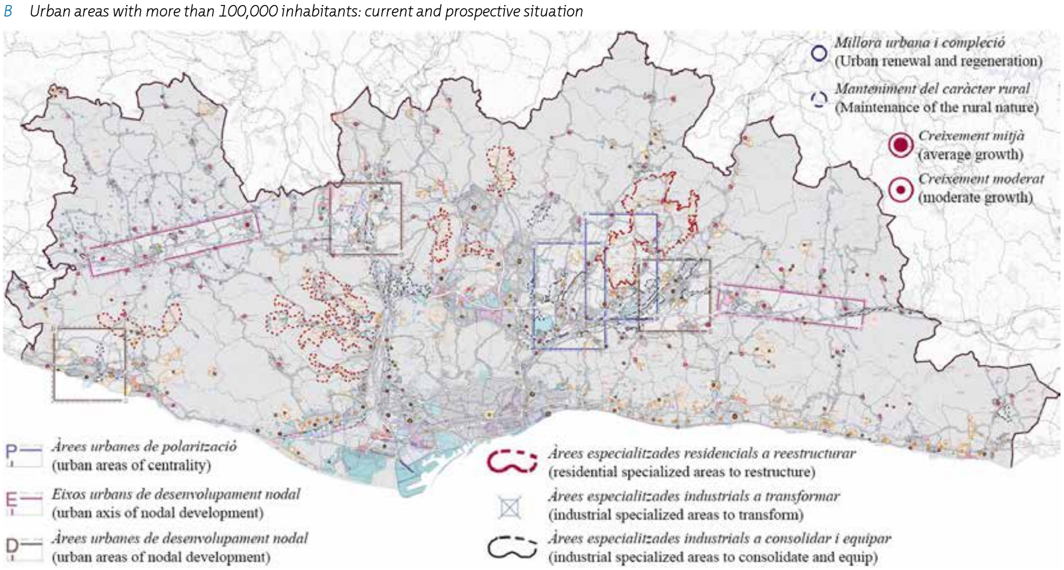
As the Barcelona Metropolitan Territorial Plan emphasizes (p.153), the implementation of this polycentric model for the Barcelona metropolitan region adds value compared to the other alternative territorial models. It could also be coherently applied to the rest of the Catalan territory (see Figure 4.4b). This would imply a territorial model based on focusing prospective urban growth on cities located beyond the Barcelona metropolitan region, selected according to their size, connectedness to the main infrastructures (highway and railway networks), and the availability of land for development in the surrounding areas. In that regard, this proposal would not only enrich the set of Catalan cities with more than 100,000 inhabitants, such as Tarragona, Reus, Lleida, and Girona, together with Barcelona and the seven Metropolitan Arch cities but also promote the increased rank of other minor cities, such as Igualada, Manresa, Vic, and Figueres. Moreover, the Barcelona Metropolitan Territorial Plan states (p.129) that this polycentric configuration would enable the satisfaction of general planning objectives related to open spaces, urban settlements and mobility infrastructures. It also contributes to developing compact and dense cities that, although efficiently connected, have adequate physical distance between them to maintain and preserve open spaces and natural corridors. Additionally, this plan serves cities with a relatively low concentration of infrastructures and personal services that require a critical mass for further development.



A The urban settlement proposal of the Barcelona Metropolitan Territorial Plan: the polycentric territorial model



B Urban areas with more than 100,000 inhabitants: current and prospective situation



C Urban strategies for the Barcelona Metropolitan Territorial Plan's polycentric proposal

FIGURE 4.4 The polycentric territorial model proposed by the 2010 Barcelona Metropolitan Territorial Plan

Source: Generalitat de Catalunya (2010).

To develop the polycentric model and establish the rules for future urban development, the Barcelona Metropolitan Territorial Plan overlaps the previous classification of urban settlements with a set of urban strategies. Essentially, what the Barcelona Metropolitan Territorial Plan proposes is a territorial division into three distinct sub-metropolitan areas, each of which follows a different set of urban strategies (Figure 4.4c). The first sub-metropolitan area identified by the Barcelona Metropolitan Territorial Plan is the *continus urbans intermunicipals* (inter-municipal urban continuums), for which different development rules are established in accordance with that area's characteristics[11]. For instance, the Barcelona Metropolitan Territorial Plan prescribes (p. 155) that the major growth foreseen for the Barcelona metropolitan region will be concentrated in areas that reinforce the polycentric structure (i.e., the Metropolitan Arch cities and their inter-municipal urban continuums). This foreseen growth is defined by grid pattern development in the case of urban areas of nodal development (e.g., Vilanova I la Geltrú, Martorell and Granollers), concentration of urban facilities and services in relation to the axis of nodal development (see Figure 4.4c), and concentration of mixed (residential and economic activities) developments in urban areas of centrality (e.g., Riera de Caldes and Tenes). The second sub-metropolitan area is the *nuclis i àrees urbanes* (centers and urban areas), for which the Barcelona Metropolitan Territorial Plan establishes various strategies (average or moderate growth, urban renewal and regeneration, and maintenance of the nature of rural areas) according to their characteristics, their accessibility, and the availability of developable land. Finally, the third sub-metropolitan area (p.156) is the àrees especialitzades (specialized areas), for which the Barcelona Metropolitan Territorial Plan mainly prescribes the restriction of new specialized areas in isolated low-density urban areas and the concentration of specific land uses (residential, industrial, services, etc.) in such areas to enhance their integration with other, more complex urban areas.

Therefore, it seems that this territorial development proposal combines the urban development necessary to concentrate the forecasted growth of economic activity, population, and housing with the maximum respect for open spaces and mobility infrastructures. As the Barcelona Metropolitan Territorial Plan notes (p.129), the main centers that comprise this polycentric territorial model for the Barcelona metropolitan region (Barcelona and the cities of the *Arc Metropolità*) can distribute and canalize estimated future growth in a more balanced manner; the model is the proper instrument to achieve the objectives of economic efficiency, social cohesion and environmental sustainability. This model is what mainly defines the Barcelona Metropolitan Territorial Plan's planning vision of polycentricity, which corresponds with the (extensively referenced) planning vision of polycentricity proposed by the *Pla Territorial General de Catalunya* and the planning concept of *ciutat de ciutats* (city of cities) coined by Nel·lo (2001) that departed from this vision. Next, this study will explain how this urban settlement proposal is compatible with an open-spaces and mobility-infrastructure proposal that satisfactorily accomplishes the planning objectives of the Barcelona Metropolitan Territorial Plan.

Proposals for open spaces and a mobility infrastructure

The Barcelona Metropolitan Territorial Plan defines a proposal for open spaces and a mobility infrastructure (Figure 4.5 and Figure 4.6) that aims to achieve its corresponding planning objectives (see Figure 4.1). Essentially, the open-spaces proposal is centered on organizing the land designated as 'not for building' to protect territory from urbanization and the processes that might negatively affect its landscape, environmental, inherited, and economic values. As Figure 4.5 shows, the

11 Urban centers, metropolitan strategic functional areas, urban transformation areas of metropolitan interest, urban extension areas of metropolitan interest, new centralities, residential specialized areas to restructure, industrial specialized areas to transform, industrial specialized areas to consolidate and equip, and areas to reinforce the polycentric structure.

Barcelona Metropolitan Territorial Plan designs a system of two extensive, continuous protection areas along the entire metropolitan territory and parallel to the coast, departing not only from physical and administrative reality but also from the plan's own proposal of urban settlements. Moreover, these two longitudinal open-space corridors are connected by a set of transversal ecological connectors located in the vineyard zones in the region of Alt Penedès and on the *planes del Vallès* (Vallès plains). The purpose of these transversal connectors is to combine those spaces, which already had a certain level of protection, with those that have been extended. This purpose translates into a delimited area that avoids uncontrolled urbanization, which covers 74.8% of the Barcelona metropolitan region's territory (243,143 out of the region's 323,533 hectares).

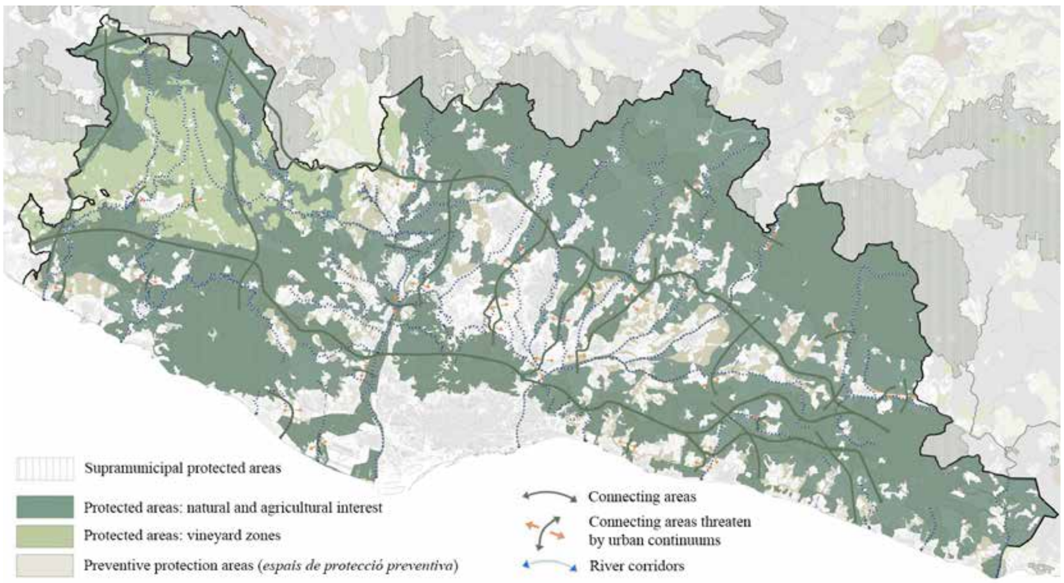
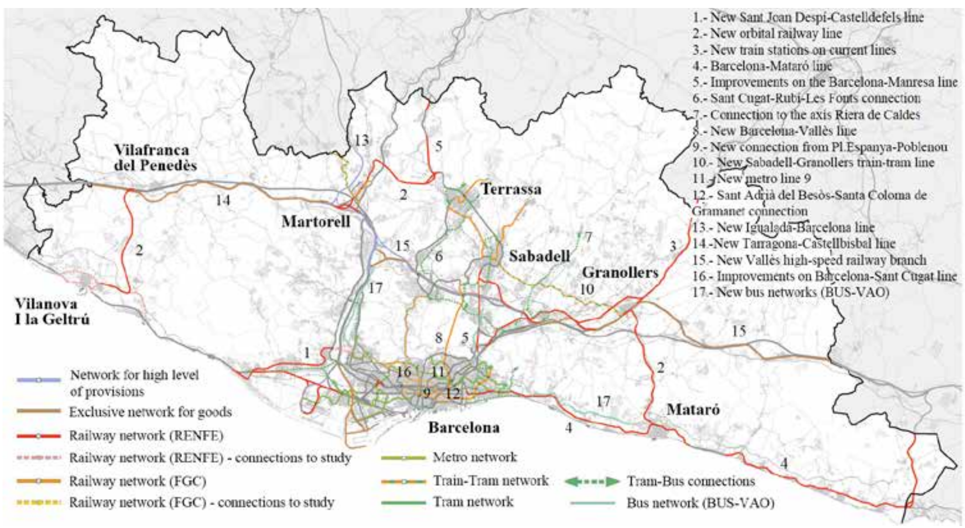


FIGURE 4.5 The 2010 Barcelona Metropolitan Territorial Plan's proposals for open spaces

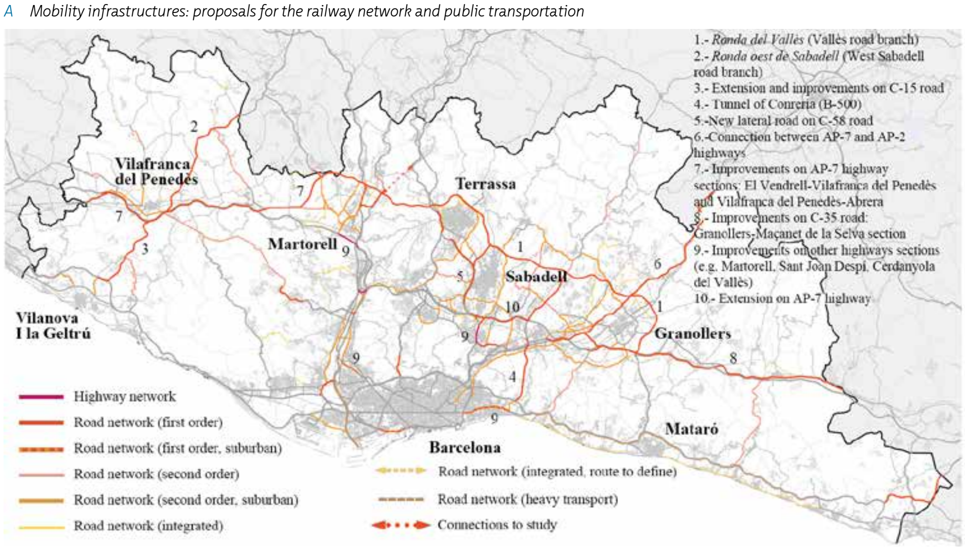
Source: Generalitat de Catalunya (2010).

The mobility-infrastructure proposal is focused on the railway network and public transportation, and the road network to enhance individuals' accessibility and connectivity with respect to both work and non-work travel, to promote a shift of travel-mode choice toward more sustainable modes of transport (public transportation, bicycling, and walking) and to contribute to organizing the urban developments on the polycentric proposal. With respect to the railway network and public transportation, the Barcelona Metropolitan Territorial Plan prescribes a set of proposals to overcome the primary limitations of these mobility infrastructures (e.g., lack of capacity to access Barcelona, low coverage in certain areas, a lack of transversal connections, few inter-connections between lines, and an insufficient network of goods). To do so, it extends and improves these infrastructure networks by considering six different types of networks: a railway network for the large-scale provision of services, a railway network for goods, networks of FGC-RENFE railways and train-trams, a metro network, a tram-bus network, and a bus network. The most important of the Barcelona Metropolitan Territorial Plan's infrastructure interventions could be the new orbital railway line (which links the seven cities of the Metropolitan Arch (see number 2 in Figure 4.6a) to reinforce its polycentric territorial model), the new railway connection between Barcelona and the cities located at Vallès Occidental (see number 8), and the train-tram connection between Sabadell and Granollers (see number 10).

In terms of the road network, the Barcelona Metropolitan Territorial Plan proposes a set of actions aimed at segregating traffic into distinct levels both to allow adequate usage of the road network and to increase its efficiency, connectivity, and integration with proposals for urban settlements and open spaces (see Figure 4.6b). The Barcelona Metropolitan Territorial Plan attempts to attain these objectives by distinguishing five categories of roads and their related roles. The first category includes highways whose function is to organize the Barcelona metropolitan region's territory related to the entirety of Catalonia's territory. The second category includes first-order roads that articulate the territory within the Barcelona metropolitan region. The third category includes second-order roads that organize the territory at the *comarcal* (regional) scale. The fourth category includes suburban roads that are essential to linking municipalities. The fifth category includes integrated roads whose role is to connect lower- and higher-ranking roads. One of the most relevant interventions is the *Ronda Vallès* (Vallès road branch), which allows greater connectivity between the cities of the Metropolitan Arch (see number 1 in Figure 4.6b), the *Conreri*a (B-500) tunnel that links Mataró with the cities located at the Vallès towards Sabadell (see number 4), and the extensions and improvements on the AP-7 highway (see number 7 and 10) that reinforce accessibility to major cities beyond Barcelona (e.g., Sabadell, Cerdanyola del Vallès, Sant Cugat del Vallès, etc.).



A Mobility infrastructures: proposals for the railway network and public transportation



B Mobility infrastructures: proposals for the road network

FIGURE 4.6 The 2010 Barcelona Metropolitan Territorial Plan's proposals for a mobility infrastructure

Source: *Generalitat de Catalunya (2010).*

Public reactions: before and after final approval

After receiving initial approval in June 2009, the Barcelona Metropolitan Territorial Plan's proposals were subjected to public consultation for one month to gather reactions from civil society, whereas administrative bodies (e.g., municipalities) had a few months to prepare their official reactions. During this period, the Department of Territorial Policy and Public Works of the Catalan Government received 462 documents containing 2,570 objections.

Most of the objections came from three distinct groups. The first group was primarily organized around a community platform known as *Plataforma per una Vegueria Pròpia*. That platform argued for the creation another *vegueria* (supraregion) in the Catalan territory, to be named *Vegueria del Penedès* and formed from the *comarques* (regions) of Alt Penedès and Garraf (regions currently belonging to the Barcelona metropolitan region) next to Anoia and Baix Penedès. The primary reason for this proposal was that the territory composed of these four regions constituted a geographical entity with a strong shared identity based on the presence of important urban centers, large rural areas of outstanding natural value, complementary economic activities and common problems. Accordingly, the *Plataforma per una Vegueria Pròpia* argued that the Barcelona Metropolitan Territorial Plan had negative effects on the identity of the landscape, balanced growth and the preservation of agricultural activities in Alt Penedès and Garraf (Vegueria Pròpia, 2009). Thus, the *Plataforma per una Vegueria Pròpia* asked the Department of Territorial Policy and Public Works to remove the regions of Alt Penedès and Garraf from the Barcelona metropolitan region and to join them to the regions of Anoia and Alt Penedès in a new planning region, for which a *Pla Territorial Parcial del Penedès* (Partial Territorial Plan of Penedès) would then be elaborated.

Ecological interest groups formed the second block of objectors. The most relevant objections came from DEPANA (League for Protecting the Natural Assets) and *Ecologistes en Acció de Catalunya* (Ecologists in action within Catalonia). DEPANA (2009) proposed four modifications to the Barcelona Metropolitan Territorial Plan proposal. First, it proposed to foster even more densification in brownfield locations by identifying and delimiting protected nature areas instead of proposing new residential development in those locations. Second, it proposed to decrease the number of new homes (approximately 500,000) that the Barcelona Metropolitan Territorial Plan forecast would be needed by 2026. Third, it proposed to define a revision cycle of 5 years to make the Barcelona Metropolitan Territorial Plan more adaptable to reality (e.g., urban settlements and infrastructures). Fourth, it proposed to revise the Barcelona Metropolitan Territorial Plan's open spaces classification to define two categories based on ecological criteria: on the one hand, natural spaces; and on the other hand, agricultural, forestry and river spaces. In addition, Ecologistes en Acció de Catalunya (2009) emphasized the Plan's lack of attention to planning an energy infrastructure (e.g., microplants to produce electricity). That group also criticized the expected rate of population, job, and housing growth in some scenarios predicted in the Barcelona Metropolitan Territorial Plan as overly optimistic in the context of the economic crisis (for instance, the milestone of 8 million inhabitants in Catalonia by 2026).

The third block of objectors included municipalities that considered certain proposals of the Barcelona Metropolitan Territorial Plan to threaten local interests. It is worth singling out the objections made by the *Via Vallès* platform because the Barcelona Metropolitan Territorial Plan's polycentric model places a great deal of emphasis on the development of the *Arc Metropolit*à cities. More specifically, Via Vallès (2009:7) notes that the Barcelona Metropolitan Territorial Plan should have recognized many more cities as new, important urban centers, including Sant Cugat del Vallès, Rubí, Cerdanyola del Vallès, Barberà del Vallès, Mollet del Vallès and Parets del Vallès (all of which are located in the regions of Vallès Occidental and Vallès Oriental).

The changes in the final, approved version of the Barcelona Metropolitan Territorial Plan do not reflect these criticisms. For instance, with respect to the *Vegueria del Penedès* demands, the Barcelona Metropolitan Territorial Plan's editorial team (see Generalitat de Catalunya, 2009b:22) responded by including (in the section *Normes d'Ordenació Territorial* (Territorial Planning Regulations)) temporal approval of the *Pla Director Territorial* (Territorial Director Plan) for the Alt Penedès, which would be the planning instrument for that region within the Barcelona metropolitan region.

After its final approval in April 2010, the Barcelona Metropolitan Territorial Plan has been primarily discussed among urban and regional planning professionals, such as scholars from Catalan universities and research institutes. Most of these professionals were enthusiastic about the Barcelona Metropolitan Territorial Plan. For example, Llop (2012) notes the importance of cooperation among distinct metropolitan agents in the elaboration of the plan, which enabled the successful inclusion of a larger number of cities (e.g., cities of the Metropolitan Arch) than before (e.g., cities included in the 1953 *Pla Comarcal* or 1976 *Pla General Metropolità de Barcelona*). Pié (2012) argues that one of the main pillars of the Barcelona metropolitan region of the future would be the project of the seven cities of l'*Arc Metropolità* because of their efforts to establish a network of cities to break Barcelona's dominance. Torres I Capell (2012) highlights that the design of the transport infrastructures—more specifically, replacing the radial model with a tangential one—the delimitation of protected natural areas and the definition of urban settlements based on the classification of centers according to size constituted the Barcelona Metropolitan Territorial Plan's three key points to plan future development.

Compared to these positive assessments, the sole critical voice was that of Solans (2012), whose study noted the shadow of the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona* on the 2010 Barcelona Metropolitan Territorial Plan caused by the arbitrary decision of the Department of Territorial Policy and Public Works of the Catalan government to base the elaboration of the Partial Territorial Plan of Penedès on the approval of the Barcelona Metropolitan Territorial Plan. That decision could provide evidence of a lack of adequate political support for the Barcelona Metropolitan Territorial Plan (such as that which the *Pla Director* received during the 1960s; see chapter 3) to overcome the administrative difficulties derived from delimiting a metropolitan territory for Barcelona that overflows the legal-administrative borders. However, the plan closely corresponds to the perceived boundaries or 'scalar consciousness' (Healey, 2006) of Barcelona's metropolitan territory. As Solans (2012:72) states, this lack of political support has led to a contradictory situation. Although the Catalan government's planning unit presented the Barcelona Metropolitan Territorial Plan as an important achievement that would finalize the planning debate in Catalonia, it later (and surprisingly) accepted the objection of the *Vegueria del Penedès*, which was dismissed during the public consultation process. The result was the elaboration of a Partial Territorial Plan that could split the Barcelona metropolitan region into two administrative territories in the coming years.

With respect to those aspects that are related to the Barcelona Metropolitan Territorial Plan's planning vision, it appears that a polycentric territorial model for the Barcelona metropolitan region is generally well received, but there is some discussion about the exact elaboration of this model. Whereas the editors of the Barcelona Metropolitan Territorial Plan, together with the leading thinkers on territorial planning, advocated the further strengthening of the seven cities that form the metropolitan body of l'*Arc Metropolità*, the *Via Vallès* platform advocated for the importance of other centers located in the regions of Vallès Occidental and Vallès Oriental, in which future development should also be concentrated. Perhaps this may reveal a political dimension to the elaboration of the Barcelona Metropolitan Territorial Plan, in light of the fact that after the 2007 municipal elections, six of the seven cities that form l'*Arc Metropolità* were ruled by the Socialist Party (PSC-PSOE), which also headed the Catalan government that developed the Barcelona Metropolitan Territorial Plan. In contrast, the Socialist Party has less support in the additional cities suggested by the *Via Vallès* platform, for example, Sant Cugat del Vallès.

§ 4.3 Territorial dynamics versus the territorial model

This section presents a demographic analysis at the municipal and regional levels to determine whether territorial dynamics correspond to the territorial model proposed in the Barcelona Metropolitan Territorial Plan. This addresses the feasibility of such a territorial model because, if that model was inconsistent with developments on the ground (for instance, further concentration in Barcelona), it could be difficult to achieve. Conversely, if current dynamics would support the polycentric model, for instance, when the cities of the *Arc Metropolità* experience stronger population growth, an enhanced implementation of the Barcelona Metropolitan Territorial Plan's planning vision could result. When studying these territorial dynamics, I focus on spatial-demographic trends; this analysis will suggest whether it is useful to rethink the territorial model for the Barcelona metropolitan region when there are significant discrepancies between the desired polycentric development of the Barcelona Metropolitan Territorial Plan and the territorial dynamics on the ground.

Figure 4.7 shows thirty years (1981-2012) of absolute and relative demographic trends in Catalonia's 41 regions[12]. The regional demographic dynamics can be characterized as follows. First, the Barcelonès region, which includes the city of Barcelona, witnessed a significant population decline (-200,439 inhabitants). This corresponds to a relative decline of -8.17%. Nevertheless, after two decades of losing population (1981-2001), the Barcelonès region started to grow again between 2001 and 2012 at a rate of more than 7%. Second, it appears that this population decentralization has primarily been absorbed by the regions that are part of the Barcelona metropolitan region because few regions beyond the Barcelona metropolitan region experienced considerable population growth (some even experienced population decline (see Figures 4.7a-b)). Thus, those regions that saw the steepest increase in population are located in the Barcelona metropolitan region: Vallès Occidental (+299,849 inhabitants and +50.11%), Baix Llobregat (+233,338 inhabitants and +40.69%), Maresme (+182,960 inhabitants and +72.17%), Vallès Oriental (+177,537 inhabitants and +78.87%), and Garraf (+147,107 inhabitants and +112.94%). The Vallès Occidental region has experienced the greatest population growth since 1981 in absolute terms. It grew continuously decade-by-decade, making it the second-largest region in Catalonia. However, except for the Barcelonès region itself, all of the regions in the Barcelona metropolitan region grew. The important population growth (absolute and relative terms) that can be seen in Catalonia's coastal regions (e.g., Alt Empordà, Baix Penedès) is not necessarily related to the decline of Barcelona's region; urbanization pressure there is also attributable to tourism, for instance, the development of second homes.

Figures 4.8 and Table 4.1 report population trends on the municipal scale. These trends generally correspond with regional trends. The loss of dominance (at least in terms of population size) experienced by the Barcelonès region can also be seen on this scale. The city lost more than 130,000 inhabitants (-7.51%). The same is true for some adjacent cities that are part of the same built-up area, such as L'Hospitalet de Llobregat (-38,017 inhabitants -132.88%) and Santa Coloma de Gramanet (-20,020 inhabitants and -14.24%). Some capital cities of the regions in Catalonia have experienced considerable growth since 1981, including Lleida (+33,020 inhabitants and +30.91%), Reus (+27,966 inhabitants and +35.29%), El Vendrell (+24,986 inhabitants and +214.27%), and Tarragona (+24,842 inhabitants and +22.77%).

12 The administrative division of Catalonia's territory into 41 *comarques* (regions), as explained in chapter 3, is rooted in the 1936 *Divisió Territorial de Catalunya* (Territorial Division of Catalonia), approved by the *Generalitat de Catalunya* (Government of Catalonia).

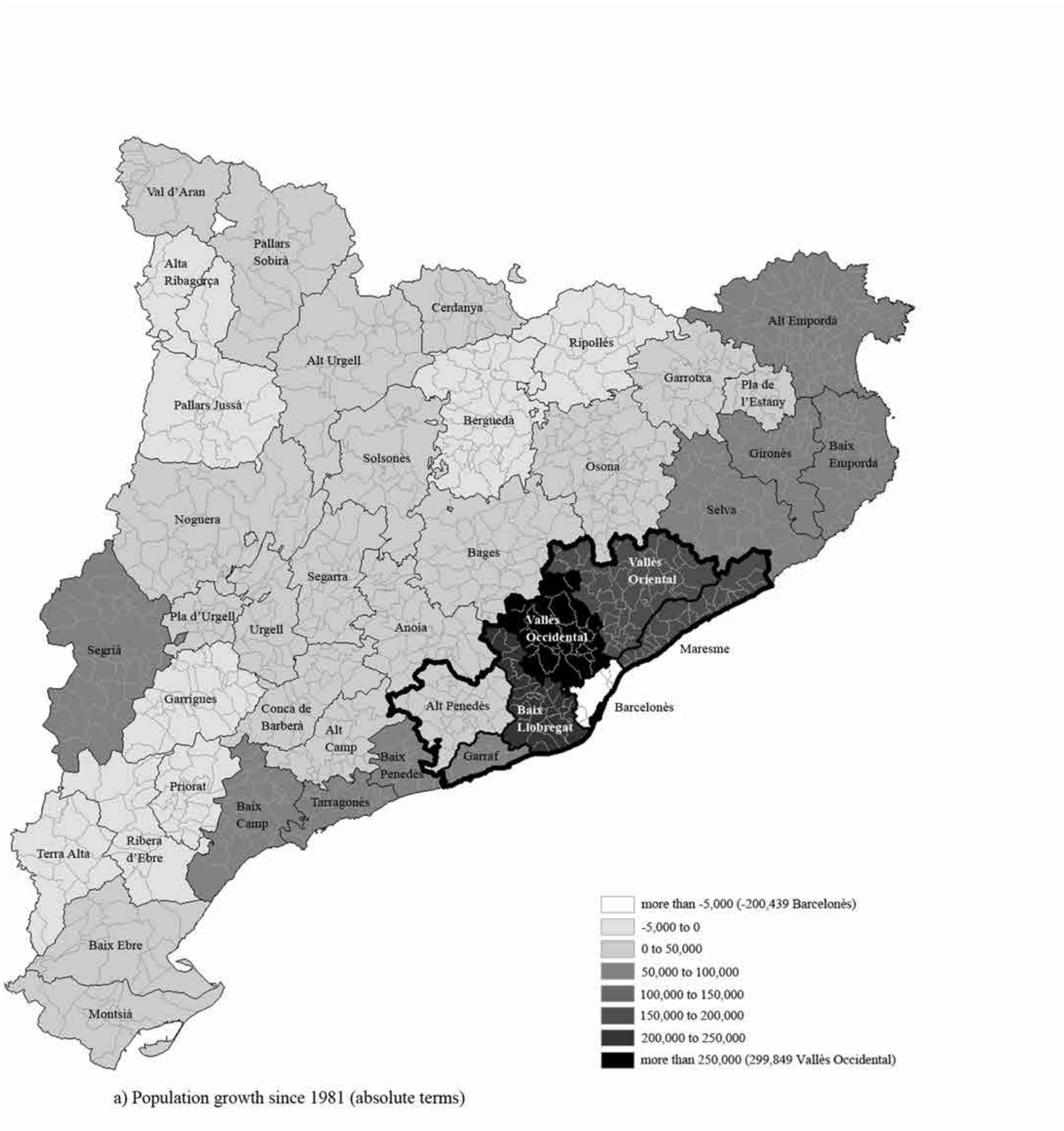
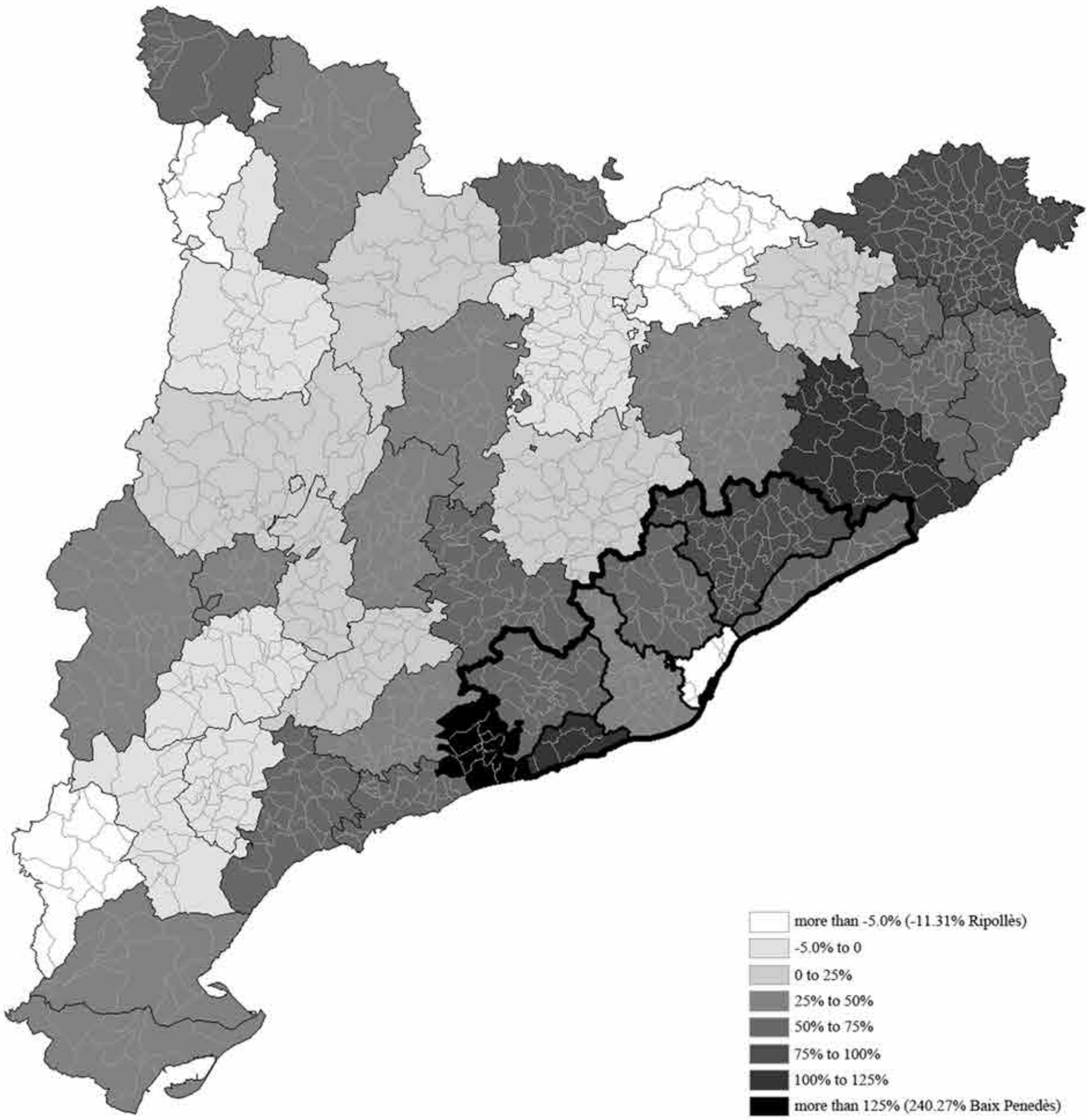


FIGURE 4.7 Population evolution of Catalonia's regions between 1981 and 2012

Note(s): data comes from the census (1981) and municipality register (2012) provided by INE (Instituto Nacional de Estadística) and IDESCAT (Institut d'Estadística de Catalunya), respectively.



b) Population growth since 1981 (relative terms)

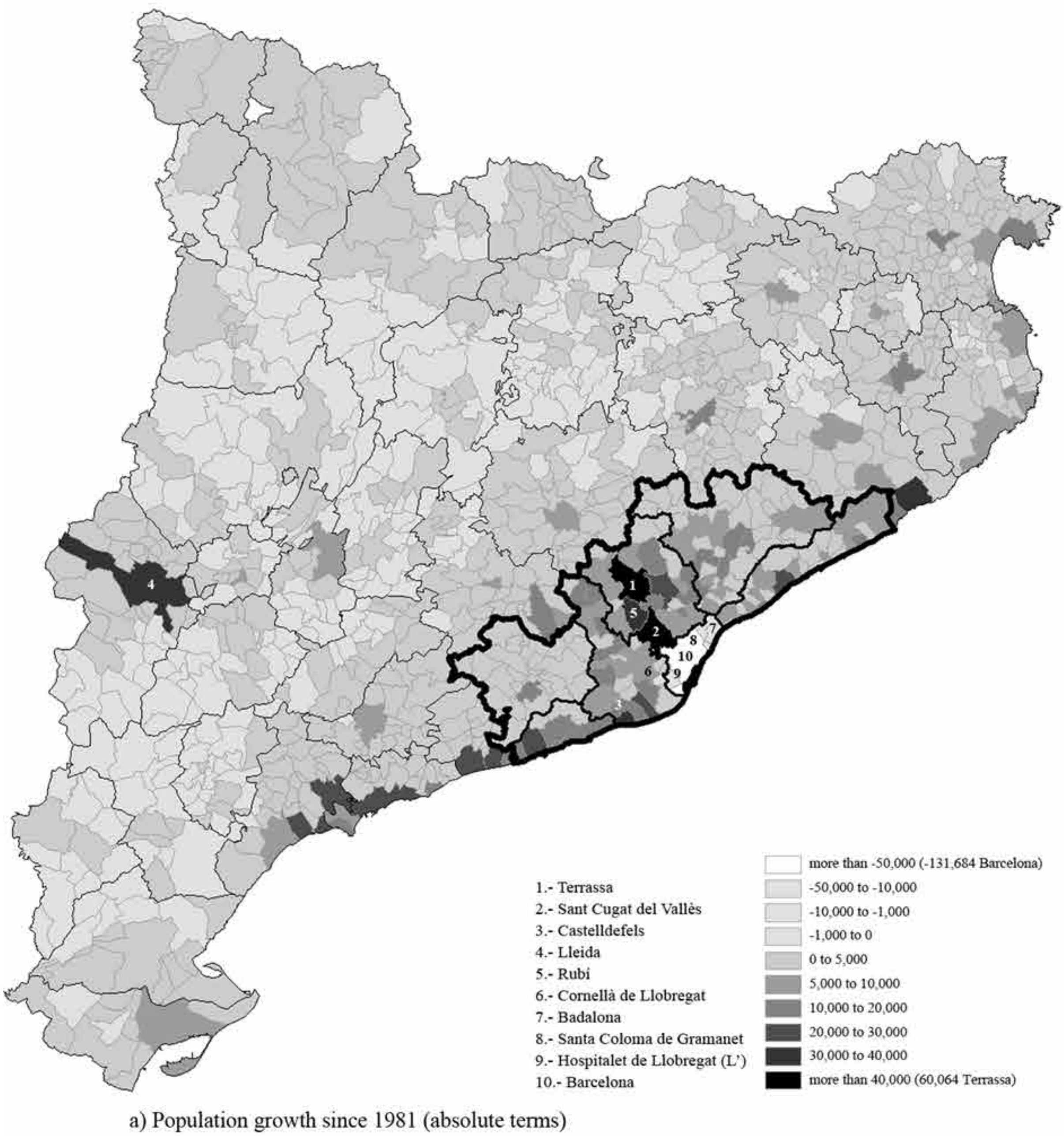
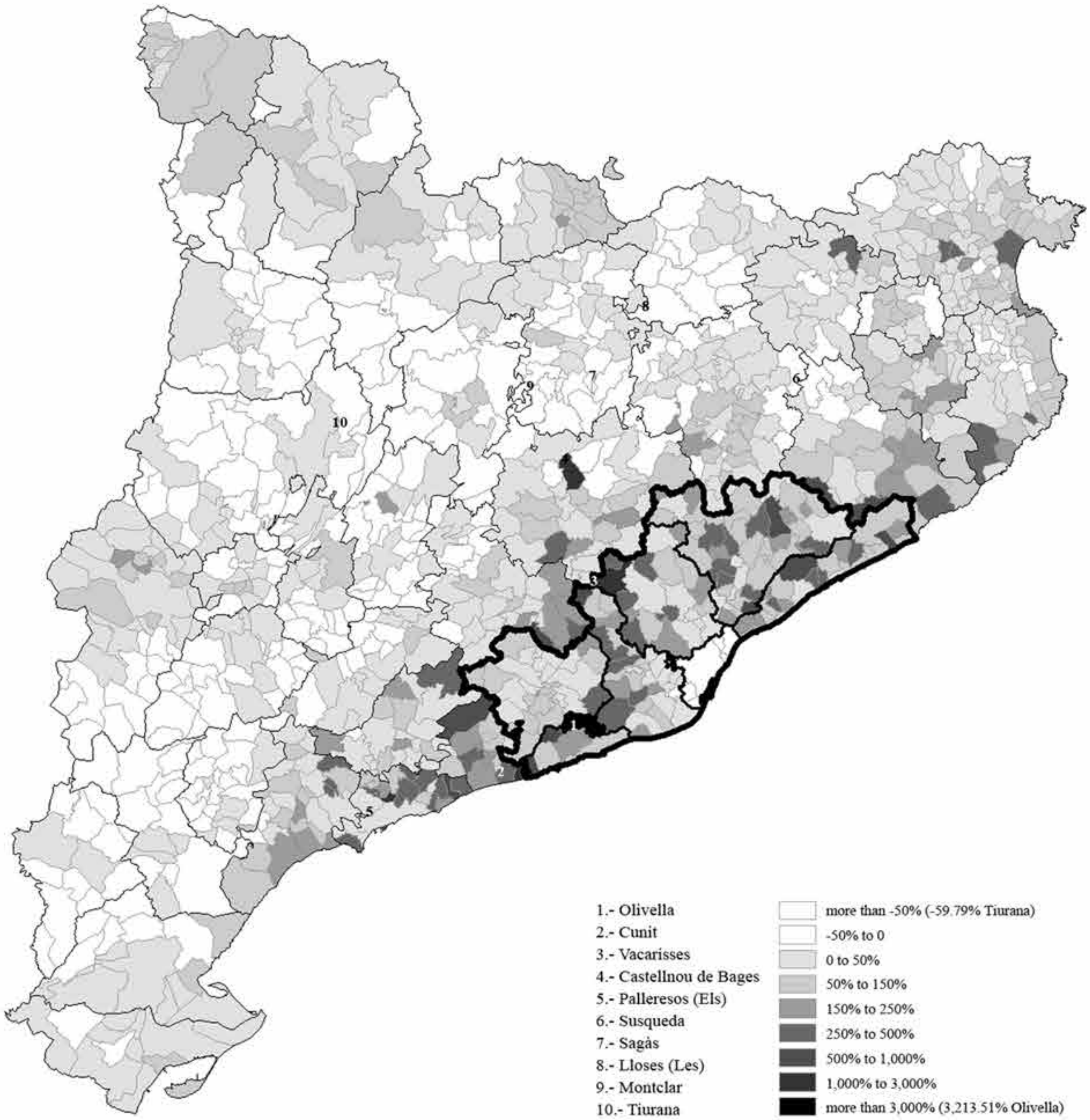


FIGURE 4.8 Population evolution of Catalonia's municipalities between 1981 and 2012

Note(s): data comes from the census (1981) and municipality register (2012) provided by INE (Instituto Nacional de Estadística) and IDESCAT (Institut d'Estadística de Catalunya), respectively.



b) Population growth since 1981 (relative terms)

MUNICIPALITY	REGION	BMR	POPULATION 1981	POPULATION 2012	TREND SINCE (ABSOLUTE) 1981	GROWTH RATE 1981-1991	GROWTH RATE 1991-2001	GROWTH RATE 2001-2012	TREND SINCE (RELATIVE) 1981
Terrassa	Vallès Occidental	Yes	155,614	215,678	60,064	1.57%	10.56%	23.42%	38.60%
Sant Cugat del Vallès	Vallès Occidental	Yes	30,633	84,946	54,313	27.11%	43.37%	52.16%	177.30%
Castelldefels	Baix Llobregat	Yes	24,697	62,989	38,292	33.69%	41.70%	34.63%	155.05%
Lleida	Segrià	No	106,814	139,834	33,020	4.94%	0.84%	23.70%	30.91%
Rubí	Vallès Occidental	Yes	43,839	74,484	30,645	14.98%	19.64%	23.52%	69.90%
Lloret de Mar	Selva	No	10,463	40,837	30,374	43.53%	43.75%	89.16%	290.30%
Reus	Baix Camp	No	79,245	107,211	27,966	10.63%	2.72%	19.05%	35.29%
Mataró	Maresme	Yes	97,008	124,084	27,076	4.64%	5.60%	15.76%	27.91%
Vendrell (El)	Baix Penedès	No	11,661	36,647	24,986	32.19%	54.23%	54.15%	214.27%
Tarragona	Tarragonès	No	109,112	133,954	24,842	0.95%	4.54%	16.33%	22.77%
Vilanova i la Geltrú	Garraf	Yes	43,833	66,591	22,758	4.63%	16.48%	24.65%	51.92%
Cambrils	Baix Camp	No	11,136	33,535	22,399	30.85%	43.96%	59.87%	201.14%
Viladecans	Baix Llobregat	Yes	43,358	65,188	21,830	11.38%	18.30%	14.10%	50.35%
Sabadell	Vallès Occidental	Yes	186,123	207,938	21,815	1.76%	-2.24%	12.30%	11.72%
Calafell	Baix Penedès	No	4,597	24,672	20,075	55.88%	85.98%	85.13%	436.70%
Blanes	Selva	No	20,353	39,785	19,432	26.09%	22.87%	26.17%	95.47%
Salou	Tarragonès	No	*	26,601	19,337**	*	92.07%	90.66%	266.20**
Sant Pere de Ribes	Garraf	Yes	10,517	29,149	18,632	29.90%	67.63%	27.28%	177.16%
Sitges	Garraf	Yes	11,844	29,039	17,195	10.68%	55.20%	42.73%	145.18%
Mollet del Vallès	Vallès Oriental	Yes	35,480	52,242	16,762	15.21%	14.73%	11.40%	47.24%
Sant Adrià de Besòs	Barcelonès	Yes	36,397	34,482	- 1,915	- 6.16%	- 5.02%	6.30%	- 5.26%
Cornellà de Llobregat	Baix Llobregat	Yes	91,563	87,458	- 4,105	- 7.25%	- 4.45%	7.78%	- 4.48%
Badalona	Barcelonès	Yes	229,780	220,977	- 8,803	- 4.81%	- 4.45%	5.73%	- 3.83%
Santa Coloma de Gramenet	Barcelonès	Yes	140,613	120,593	- 20,020	- 5.32%	- 12.82%	3.90%	- 14.24%
Hospitalet de Llobregat (L')	Barcelonès	Yes	295,074	257,057	- 38,017	- 7.62%	- 11.04%	6.01%	- 12.88%
Barcelona	Barcelonès	Yes	1,752,627	1,620,943	- 131,684	- 6.22%	- 8.41%	7.68%	- 7.51%

TABLE 4.1 Population evolution of Catalonia's municipalities between 1981 and 2012

*Note(s): sorted by population trend since 1981 (absolute terms). Data comes from the census (1981, 1991, 2001) and municipality register (2012) provided by INE (Instituto Nacional de Estadística) and IDESCAT (Institut d'Estadística de Catalunya), respectively. * Refers to those municipalities that did not exist in 1981 and ** refers to the population trend since (relative) 1991.*

As these large (more than 100,000 inhabitants) cities grow, it would seem that organizing future urbanization in a polycentric model, as proposed by the Barcelona Metropolitan Territorial Plan, would be a coherent plan. There has been discussion about the issue of whether more cities than the seven included in the *Arc Metropolità* should be considered as important urban growth poles. The numbers show that strong population growth in the Vallès Occidental region is not exclusively associated with the cities belonging to the *Arc* such as Sabadell (+21,815 inhabitants and +11.72%) and Terrassa (which experienced the greatest absolute growth, +60,064 inhabitants, corresponding to +38.60%). Both absolute and relative growth were very substantial in other cities that are not included in the *Arc*, such as Sant Cugat del Vallès (+54,313 inhabitants and +177.30%) and Rubí (+30,645 inhabitants and +69.90%). Moreover, the growth rates experienced by the other cities of the *Arc Metropolità* (Mataró, Vilanova I la Geltrú, Granollers, Vilafranca del Penedès, and Martorell) have been less prominent. In conclusion, this analysis has revealed that although the polycentric territorial model for the rest of the Catalan territory proposed by the Barcelona Metropolitan Territorial Plan is in line with

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recent population trends, these dynamics suggest that cities in the Barcelona metropolitan region other than those identified in the plan have acted as urban growth poles. Consequently, those other cities also contribute to defining the polycentric structure proposed by the Barcelona Metropolitan Territorial Plan.

§ 4.4 Conclusion and discussion

A close examination of the 2010 Barcelona Metropolitan Territorial Plan has illustrated not only whether its polycentric model has become the preferred spatial development strategy over other alternative territorial models but also whether this polycentric development corresponds to actual development in the Barcelona metropolitan region. Moreover, it has exposed that some shortcomings in the application of a polycentric development strategy to spatial plans stem from the lack of a more evidence-informed planning and thus, how polycentric development could be interpreted in planning to be more connected to the current debate on polycentricity in research. This examination of the Barcelona Metropolitan Territorial Plan by studying its elaboration model and public reactions and analyzing population trends has led to two main conclusions.

First, the analysis of recent population dynamics has noted some discrepancies between the polycentric model of the Barcelona Metropolitan Territorial Plan and how it is elaborated by defining the nodes of this polycentric model that should accommodate future urban development. Population dynamics reveal that cities that had concentrated urban dynamics and canalized urban development in the last few decades were not necessarily the main poles of polycentric development (i.e., Barcelona and the cities of the *Arc Metropolità*), according to the Barcelona Metropolitan Territorial Plan. Cities located in the region of Vallès Occidental such as Sant Cugat del Vallès and Rubí not only have experienced stronger growth than most of the *Arc Metropolità*'s cities (e.g., Vilafranca del Penedès, Vilanova I la Geltrú, Granollers, and Martorell) but also have a larger population than some of these *Arc Metropolità*'s cities. Consequently, the analysis signals that these population dynamics have either been overlooked when studying territorial dynamics in step 3 of the elaboration of the Barcelona Metropolitan Territorial Plan (see Figure 4.1), or they have been ignored for other reasons. Rumor has it that these reasons might have been political, but the evidence for that conclusion is only anecdotal.

Second, public consultation on the proposed plan resulted in the claim that a larger set of cities in the regions of Vallès Occidental and Vallès Oriental should act as important centers to organize the future development of the Barcelona metropolitan region. This claim was supported by existing urban dynamics. However, the editors of the Barcelona Metropolitan Territorial Plan (who belong to the Department of Territorial Policy and Public Works of the Catalan government, which was under socialist rule) identified as growth poles only cities that were ruled by the Socialist Party at the time of writing (with one exception). Furthermore, this selection of cities, and especially, their proposed roles, was based strictly on size. This hierarchical system is at odds with the idea of a polycentric network system that allows cities in an urban network to perform complementary roles and in which the size and function of cities therefore become increasingly disconnected. Perhaps if the Barcelona Metropolitan Territorial Plan's operational model had considered, for example, the sectoral and functional (occupational) geography of the knowledge-based economy in the Barcelona metropolitan region, paying attention to its trends and to the complementary relationships among cities, this contradiction could have been avoided.

On a related note, the Barcelona Metropolitan Territorial Plan's operational model has two additional shortcomings that are relevant: (1) the lack of an empirical analysis that aims to consider a comprehensive identification and measurement of polycentricity on the metropolitan-region scale; and (2) the influence of a polycentric territorial model's development on the performance of metropolitan regions. Whereas the Barcelona Metropolitan Territorial Plan assumes a priori that the territorial reality of the Barcelona metropolitan region could support its territorial vision based on implementing a polycentric network development policy, this assumption cannot be taken for granted, as highlighted in chapter 2 (see sections 2.2 and 2.4). Moreover, although the Barcelona Metropolitan Territorial Plan links a polycentric territorial model with the planning objectives developed at the beginning of its elaboration process, this linkage is not necessarily self-evident because—as mentioned in chapter 2 (see section 2.3)—scholars have not found conclusive evidence of the benefits of polycentricity. The scientific basis of the Barcelona Metropolitan Territorial Plan therefore would be more robust if we could verify the assumed relationship between its polycentric territorial model and the territorial reality, along with the achievement of the model's planning objectives based on enhancing the economic efficiency, social cohesion and environmental sustainability of the Barcelona metropolitan region.

Consequently, from my perspective, these conclusions imply that the Barcelona Metropolitan Territorial Plan does not represent the end of the planning debate in Barcelona-Catalonia, as its editors stated. However, my use of population as a sole indicator is not enough to provide a more robust approach to the concept of polycentricity, an empirical underpinning of the link between polycentricity and performance of metropolitan areas and thus, which territorial model is best for Barcelona. The following chapters develop distinct conceptual frameworks and empirical analyses to address these aspects. Chapter 5 addresses the identification of centers in metropolitan areas.

PART 3 Polycentricity on the Intra-urban scale

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5 Towards a new method of identifying centers in metropolitan areas

§ 5.1 Introduction

The polycentric model has been presented as the most suitable spatial organization for metropolitan areas from an economic, social and environmental perspective, and we have observed how this model has been advocated in spatial development strategies. Although much is being claimed for the polycentric model, little has been proven, as discussed in chapter 2 (section 2.3). The first step in assessing these claims is to develop a sound method of identifying centers in metropolitan areas. A multitude of methods for doing so exist; often, those methods are closely linked to the various pathways from which polycentricity can emerge. Accordingly, they are particularly geared toward identifying either centers that arise through decentralization or centers that arise through incorporation-fusion. Whereas a strongly US-based literature has developed several identification methods based on employment density functions to explain the rise of the polycentric model (e.g., McMillen and Smith, 2003) resulting from the decentralization of employment, population, and urban functions (Gordon and Richardson, 1996), a more European literature has addressed the functional relationships between cities (e.g., Veneri, 2010a) to explore their incorporation-fusion into a polycentric metropolitan area (Champion, 2001). However, none of the methods of identifying centers has really taken into account that the formation of polycentric urban systems arises out of a combination of these pathways. Given that not all of the centers in North America are the result of recent decentralization trends, nor are all of the centers in European urban systems composed of once-distinct and independent urban identities that have been incorporated or fused into a metropolitan area (e.g., Anas et al., 1998; Hohenberg and Lees, 1995), it can be argued that an identification method should consider both possibilities.

The aim of this chapter is twofold. First, it aims to connect these two trains of thought in a novel, integrated method of identifying the centers of a polycentric metropolitan area. To do so, the spread of employment in a metropolitan area and the functional relationships between urban areas are analyzed to identify both centers and their genesis (e.g., decentralization or incorporation-fusion). Using this method, this study identifies centers in the Barcelona metropolitan region and their development since 1991. In addition, this research applies other methods of identifying centers, again using the Barcelona metropolitan region as a case study.

This leads to the second aim of this chapter, which is to compare the results of various identification methods. To that end, I compare the centers that are proposed by the 2010 Barcelona Metropolitan Territorial Plan. The results are benchmarked against both the question of where actual urban development has taken place and the issue of their fit with the theoretical and empirical (polycentric) models, as suggested by the economics literature. This will lead to a conclusion about which method of identifying centers is the best for subsequently investigating the link between polycentricity, performance and planning in the remainder of this thesis. Therefore, this chapter answers the specific research question (see section 2.5 in chapter 2) of whether an empirical method of identifying centers is more accurate than the approach used by the 2010 Barcelona Metropolitan Territorial Plan in defining the polycentric model in the Barcelona metropolitan region. Answering this specific research question must be considered an essential step not only in exploring the economic, social, and environmental (dis)advantages of polycentric development but also in translating these estimated effects into spatial planning policies (see Figure 1.3 in the introduction to this thesis). For instance, because differences in a metropolitan area's centers could lead to divergent research findings on the link between polycentricity and performance, a better understanding of the costs and benefits of a polycentric structure relies on the correct identification of those centers (see chapter 2).

Many novelties will be introduced when evaluating the different identification methods against their fit with the theoretical and empirical (polycentric) models adopted in the economics literature. These novelties are derived from a new, theory-informed conceptualization of what a center is, namely that centers are not only places with the highest level of agglomeration economies in a metropolitan area but also places that cast the most wide-ranging (spatially), powerful agglomeration shadows over their surroundings. This concept is studied in a manner that is not exclusively static; instead, it is also placed into dynamic perspective by focusing on employment density growth in these surroundings. Additionally, the empirical framework built to evaluate identification methods not only addresses the econometric issues of recursive causality and spatial autocorrelation but also considers the role played by infrastructure improvements.

The rest of the chapter is organized as follows. Section 5.2 reviews the current theoretical and methodological frameworks for center formation in polycentric metropolitan areas. Section 5.3 reviews existing methods of identifying centers, distilling some of the primarily challenges that arrive when attempting to improve those methods. Section 5.4 explains the novel method used by this study. Section 5.5 presents the potential centers identified using this method and compares the results with those of other well-known methods. Sections 5.6 and 5.7 address the issue of which method most accurately identifies the centers of the Barcelona metropolitan region. Section 5.6 compares the outcomes of the new method with actual urban developments on the ground. Section 5.7 builds an empirical framework to evaluate which method fits best with the definition of centers found in economic theory. The results of applying this framework are presented in section 5.8. Finally, section 5.9 presents the main conclusions.

§ 5.2 The formation of centers

The rise of the polycentric model

To identify centers, one must understand how and why they arise. Several theories attempt to explain the formation of centers, and agglomeration economies and agglomeration diseconomies play a central role in such explanations. Based on a theoretical framework, the models coined by the New Urban Economics (e.g., Anas and Kim, 1996; Fujita and Owaga, 1982; Fujita et al., 1997; White, 1999) have noted that agglomeration economies can be defined as increased outputs and reduced costs when firms decide to co-locate in certain areas of a metropolitan space. In these terms, following Fujita and Owaga (1982:63), the urban structure can be treated as follows: "*the outcome of interaction between and within firms, which encourages the spatial concentration by reason of agglomeration economies, and between households which follow closely the employment distribution because the costs of residence-to-work commuting.*" Thus, it could be defined as population and job level of spatial concentration and distribution in a metropolitan area (Anas et al., 1998). This definition of the urban structure therefore suggests that the level of agglomeration economies is dependent on the density level of firms at each location, thus leading to the rise of distinct spatial organizations, such as those that are polycentric or dispersed.

The notion of agglomeration economies discussed above can also be found in Alonso (1964), Muth (1969) and Mills (1972), who have studied the monocentric model focusing on the bid rent theory. This theory assumes that an urban area has a single employment center that allocates all jobs. Households trade off accessibility to this center against land and housing costs to maximize their utility. This assumption means that as the distance to this single center increases, the cost of residence-to-work commuting is compensated by lower land rents that are also translated into lower densities. The New Urban Economics literature defined the theoretical monocentric model as the outcome of conflicting forces of agglomeration economies in export production and transport costs of workers who commute to the central city (workers bid to locate their households near the central city). This definition implies that the highest level of agglomeration economies is in the central city because there are certain gains from interaction between and within firms that are concentrated in this center, and these agglomeration benefits decline with distance from the central city (the assumption being that firms' interactions depend on the distance between them). For example, if firms remain concentrated in the central city, they may enjoy face-to-face communication (Sullivan, 1986), intermediate inputs and interindustry linkages (Anas and Kim, 1996), and non-pecuniary production (technological) externalities (Fujita and Owaga, 1982; Fujita et al., 1997), among other agglomeration benefits, as suggested by the agglomeration theory of the New Urban Economics.

Based on this interplay between urban structure and agglomeration economies, New Urban Economics models have also predicted the rise of a polycentric model. This prediction is based on the reformulation of the monocentric model by accepting that several centers co-exist in a metropolitan area. The key theoretical point coined by these models introduces the existence of agglomeration diseconomies. Agglomeration diseconomies are the costs stemming from agglomeration (e.g., congestion, land prices, etc.), and must be considered a centrifugal force that potentially leads to a relocation of firms (and jobs) located in the central city; however, the simultaneous need for agglomeration economies would imply that some of these firms and jobs concentrate again in the metropolitan peripheries, forming new centers (Anas et al., 1998; White, 1999). This is how New Urban Economics models explain the formation of centers. When a suburban area develops some of the agglomeration economies that genuinely exist in the central city and combines those economies with its own location advantages (e.g., cheaper land, access to less-congested infrastructure), a sufficient number of firms would decentralize and become concentrated, thus forming a center. Over time, this formation of centers through decentralization may cause workers to bid to locate their households not only close to the central city but also close to this new center because of the potential savings in commuting costs. Indeed, New Urban Economics models such as those in Fujita and Owaga (1982) and Fujita et al. (1997) predict that although firms' density (and employment density) decreases with distance from the central city, it will begin to increase as it approaches the new center.

The rise of the polycentric model following the New Urban Economics framework seems to be more closely related to the pattern of the North American urban systems than the European one. However, as mentioned previously, the process of the concentrated decentralization of employment, population, and urban functions is not the only pathway to polycentricity. Perhaps the theoretical framework that best explains the rise of the polycentric model through the functional integration of centers, which is more associated with evolving European urban systems (Champion, 2001), is found in the theoretical models of the New Economic Geography that generally build on Central Place Theory.

Essentially, New Economic Geography models can be perceived as a complementary theoretical body to the New Urban Economics models because they also consider agglomeration economies and agglomeration diseconomies to explain changes in urban structure. Moreover, they enable the study of certain issues that New Urban Economics models did not consider, such as urban hierarchy and the interaction pattern of centers. More specifically, New Economic Geography models introduce agglomeration economies through product variety in consumption goods, economies of scale, and the mobility of workers along with the agglomeration diseconomies associated with transport costs (e.g., Fujita and Mori, 1997; Fujita et al., 1999a). The interplay between these two forces is important to explain the formation of specialized cities or centers that are functionally integrated. Additionally, the New Economic Geography allows a less-hierarchical reinterpretation of urban hierarchies than does Central Place Theory.

In extending Central Place Theory, the New Economic Geography formalizes the polycentric model through decreased transport costs, which in turn enables increased interactions among centers and their market areas, thus implying the functional integration of centers (whether of similar or distinct rank) into a metropolitan entity. This integration may cause centers to become more specialized and complementary to each other, capturing a more extensive and overlapping market area in which they can also achieve the advantages of localization economies without having to give up their diverse economic base to serve wider markets (e.g., Batten, 1995; Camagni and Salone, 1993). Moreover, like New Urban Economics models, New Economic Geography models take into account the geographical distances from centers over which agglomeration economies can occur (attenuation of agglomeration economies with greater distance from centers). In the New Economic Geography, the geographic scope of agglomeration economies can be understood through the concept of the 'agglomeration shadow'. This concept refers to the existence of agglomeration shadows or *growth shadow effects* from centers over their surrounding areas, meaning that the number of firms and urban development (growth) in areas near these centers will be limited by fierce competition effects (see, e.g., Fujita et al., 1999a; Partridge et al., 2009a). Krugman (1993) states that the existence of these competition effects may prevent the rise of similarly sized cities too close to each other. However, the areas in which this competition effect is felt simultaneously enjoy some of the agglomeration economies of metropolitan area's centers because of their access to those centers. According to this theory, lower development in centers' surroundings than in centers indicates the presence of agglomeration economies in centers, whereas the extent to which there is a distance-decay effect (the attenuation of agglomeration economies with distance) indicates the strength of their influence (agglomeration shadow) over their surrounding areas and suggests that closer-in places' access can enable them to enjoy some of the benefits of centers.

The polycentric model: from theory to empirics

Several studies have attempted to empirically corroborate the predictions of the New Urban Economics theories that explain the rise of centers and consequently, polycentric configurations in metropolitan areas. In doing so, this body of literature has assessed whether the level of agglomeration economies experiences a distance-decay effect the further one is from the centers identified. If so, it can be argued that the existence of a polycentric model is empirically substantiated because there is an uneven spatial concentration of agglomeration economies in certain urban areas, resulting in the formation of centers beyond the central city.

To empirically test the polycentric model, scholars have developed an empirical framework in which proximity to the central city and other identified centers is statistically associated with the current level of agglomeration economies. These agglomeration economies are commonly proxied by job density and to a lesser extent, by population density because their direct measurement is not possible (see, e.g., Ciccone

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and Hall, 1996). Following this model framework, Song (1994), Small and Song (1994), McDonald and Prather (1994), McMillen and McDonald (1997), McMillen and McDonald (1998a), McMillen (2001a, 2001b, 2003b, 2004), McMillen and Lester (2003), and García-López and Muñiz (2007, 2010), among others, have proven that gross employment density decreases as distances to the central city and other identified centers increase. These studies have not only confirmed that agglomeration economies (proxied by densities) are unequally spread over the metropolitan territory but also shown the existence of polycentric spatial configurations in several metropolitan areas (e.g., in Los Angeles, Chicago, Barcelona).

Some studies, such as McMillen and McDonald (1997, 1998a, 1998b), McMillen and Lester (2003) and García-López and Muñiz (2010), have also controlled for another source of agglomeration economies that may explain firms' spatial concentration, which is not linked to cost savings from being locating close to each other in centers, but that is associated with the interindustry linkages that arise out of transportation cost savings. These may lead to the emergence of concentrations of firms near those urban areas well served by transportation networks, leading to an increase in firms' accessibility. It is important to control for these economies because doing so may imply that rise of centers near transportation axes is primarily caused by accessibility motivations, not the mutual interest of firms to locate close to each other. For example, McMillen and McDonald (1998a) have added distance to commuter train stations and highway interchanges in their model framework, whereas García-López and Muñiz (2010) have considered distance to the nearest road infrastructure. Both studies have revealed that although these effects foster higher employment concentrations, they are less important than effects derived from agglomeration economies that are internal to the group of firms concentrated in centers.

§ 5.3 Methods of identifying centers

Studies that follow the theoretical frameworks of the New Urban Economics and the New Economic Geography generally attempt to identify centers by targeting the areas with the highest level of agglomeration economies beyond the central city; these agglomeration economies are proxied by density. Two primary streams have emerged in the literature as part of the search for robust methods to objectively define a polycentric structure and maintain enough adaptability to enable a proper cross-country or metropolitan analysis. As mentioned above, the first stream largely originates in North America and focuses on employment density. The second stream is rooted more in Europe and addresses the pattern of functional relationships (flows) between cities. An analysis of more than 75 studies that aim to identify centers enables the categorization of six distinct methods of identifying centers. However, density-based methods clearly dominate.

Employment density-based methods

Density-based approaches have generally established employment thresholds to identify centers (e.g., Agarwal, 2015; García-López and Muñiz, 2007, 2010; Giuliano and Small, 1991, 1993, 1999; Giuliano et al., 2007, 2012; McMillen and Lester, 2003; McMillen and McDonald, 1997; Small and Song, 1994; Song, 1992). In many ways, this type of approach is a convenient and straightforward method because, e.g., it requires data that are often both readily available and adaptable to the local conditions, thus enabling the establishment of appropriate thresholds based on local circumstances. For example, García-López and Muñiz (2007, 2010) suggest that centers are those municipalities with gross job densities that are higher than the metropolitan average and that represent at least 1%

of total metropolitan jobs. Although this method's adaptability to local circumstances has certain advantages, it also implies that local knowledge is required to establish the appropriate cutoff points. In a sense, the process of defining the thresholds is often characterized by trial and error, making it difficult to compare metropolitan regions. This approach is also very sensitive to the demarcation of the spatial entities that are being analyzed. Datasets with small spatial units are more likely to have low-density pockets, which tend to reduce the number of identified centers.

Scholars have therefore focused on developing more broadly applicable methods to address these issues. These methods are based on identifying peaks of gross employment density at certain distances from the central city through an econometric estimation that can be either a parametric (McDonald and Prather, 1994; Suárez and Delgado, 2009) or a non-parametric function (e.g., Leslie, 2010; McMillen, 2001a, 2001b; Redfearn, 2007). The advantages and disadvantages of these second and third approaches relate to how these functions make assumptions about the distribution of the spatial units under analysis. Whereas a parametric function assumes that there is a parameter that can fix the function, a non-parametric function allows the consideration of certain neighboring observations in fitting the form of the density function. Although a parametric model identifies centers by capturing the overall employment distribution in a metropolitan area, it models employment density by specifying a general function. This means that a parametric model cannot account for the existence of centers with local employment variation (e.g., contiguous spatial units that would have appeared as an employment peak if the values of certain neighboring observations had been considered). In contrast, a non-parametric model has the disadvantage that it requires some local knowledge of the metropolitan area in advance, particularly when choosing the most suitable size of the 'window' that will define the regression's smoothing parameter used to consider the distribution of centers. This disadvantage is important because it relates to the model's ability to identify centers. The bigger the 'window', so the more observations are used for the density estimation for each data point, the smoother the density function, and thus the greater the probability of finding employment peaks even when there is no local rise in density. In addition, both of these econometric approaches may lead to the identification of what can be called 'small' centers. Spatial units that are further from the central city more easily fulfill the criterion of being important job (concentrations) peaks because their surrounding areas generally have a lower employment density. This becomes an identification issue because areas with few jobs have low levels of agglomeration economies and therefore should not be considered centers.

To address these issues, scholars have more recently developed a fourth method, which is based on the use of spatial econometric techniques to detect contiguous spatial units with a higher gross employment density than that of their surrounding areas (e.g., Guillain and Le Gallo, 2010; Guillain et al., 2006; Riguelle et al., 2007; Rodríguez-Gámez and Dallerba, 2012). These studies use local indexes of spatial autocorrelation to define the degree of clustering of neighboring spatial zones that have a high-level concentration of job density. Although this approach has clear advantages over other methods (for instance, because the concept of 'neighboring areas' is a spatial concept that is directly considered in the method), the use of local indexes of spatial autocorrelation does not completely address the issue of 'small' centers that are too easily identified. When a metropolitan area presents a high degree of spatial unit heterogeneity, then small spatial units surrounded by large spatial units can also easily fulfill the job density criteria (high-high and high-low values).

The persistent issue of identifying 'small' centers prompted scholars to propose a fifth, hybrid approach. Essentially, this method involves a two-step identification process in which a parametric approach (Vega and Reynolds-Feighan, 2008), a non-parametric approach (e.g., García-López, 2010; Gili, 2009; Lee, 2007; McMillen, 2003a), or a spatial econometric technique (Vasanen, 2012, 2013) is employed during the first phase, with accurate employment density thresholds set in the second phase. Consequently, centers are identified without the initial use of local knowledge, and the problem of identifying 'small' centers is reduced through the application of adequate thresholds after a trial-and-error process. The dominance of the threshold approach suggests that because of limitations on the ability of existing econometric methods to account for the problem of 'small' centers that are too easily identified, scholars have accepted that a certain degree of local knowledge is always necessary to identify centers.

Flow-based methods

The other stream of studies that identify polycentric structures accounts for the sixth method of identifying centers. In this approach, the identification of centers is based on indicators of interaction between urban areas (e.g., Aguilera, 2005; Roca et al., 2009; Veneri, 2010a, 2010b, 2013). The common objective is to identify urban areas that play a central role for the surrounding territory. Thus, these flow-based studies identify centers with a high degree of urban centrality that relates to their ability to supply their surrounding territory with urban functions. For example, Veneri (2010b) identifies centers in Rome and Milan using two interaction indicators: a flow-centrality ratio that approximates how each node plays a central role in the metropolitan area, and a *productive completeness* index that is based on the diversity of functions supplied by each municipality. Therefore, it can be argued that mobility-based approaches are less dependent than density-based approaches on making potentially arbitrary choices about cutoff points, although mobility-based approaches might present a lower level of adaptability to local contexts because data variations are common in the measurement of flows. In addition, it seems that flow-based approaches cannot genuinely capture the centrifugal (decentralization) forces that lead to polycentric structures because they primarily focus on analyzing the functional relationships to detect 'central cities' instead of examining the spread of employment caused by decentralization trends.

The challenges of identifying centers

One ambition of this thesis is to better understand the costs and benefits related to a polycentric structure. Because this evaluation depends on the correct identification of centers, this ambition demands that any method of identifying centers fulfill three main criteria.

First, it should consider the distinct origins of center formation (decentralization and incorporation-fusion) because those origins have an impact on the nature of agglomeration economies according to both the New Urban Economics and the New Economic Geography frameworks. Thus, the advantages related to the polycentric model could be dependent on them (see also section 2.3 in chapter 2).

Second, and on a related note, identification methods need to consider both the spatial concentration of employment in places as a proxy for their level of agglomeration economies and the flows between places as a proxy for their ability to play a central role for their surrounding territories. Each of the six identification methods entail a distinct definition of what a center is. Therefore, the definition of a center seems to be more closely related to the approach itself instead of being derived from a theoretical perspective that also includes the development trajectory of centers and the concept of agglomeration shadows. The consideration of density and flows means that attention is simultaneously paid to the concentration of employment and the centrality of places.

Third, the method should be objective, adaptable, and replicable. The primary drawbacks of the current approaches are that 'small' centers seem to be too easily identified as centers and that excessive use of local knowledge is often required (thus hampering both comparative research and replicability).

The literature review also helped identify some potential novelties. The most important of those novelties is that the idea of agglomeration shadows can be used to identify centers. An examination of the existence of agglomeration shadows indicates the presence of centers. Higher-ranked centers are likely to have larger agglomeration shadows. Two issues are relevant here: (1) the spatial extent to which there is an agglomeration shadow (spatial range); and (2) the strength of that agglomeration shadow (see Figure 5.1). Studying agglomeration shadows also enables the inclusion of a dynamic rather than a static perspective because it is possible to study not only whether the distance at which a center's agglomeration shadow is felt is increasing or decreasing but also whether the shadow has become more or less profound over time.

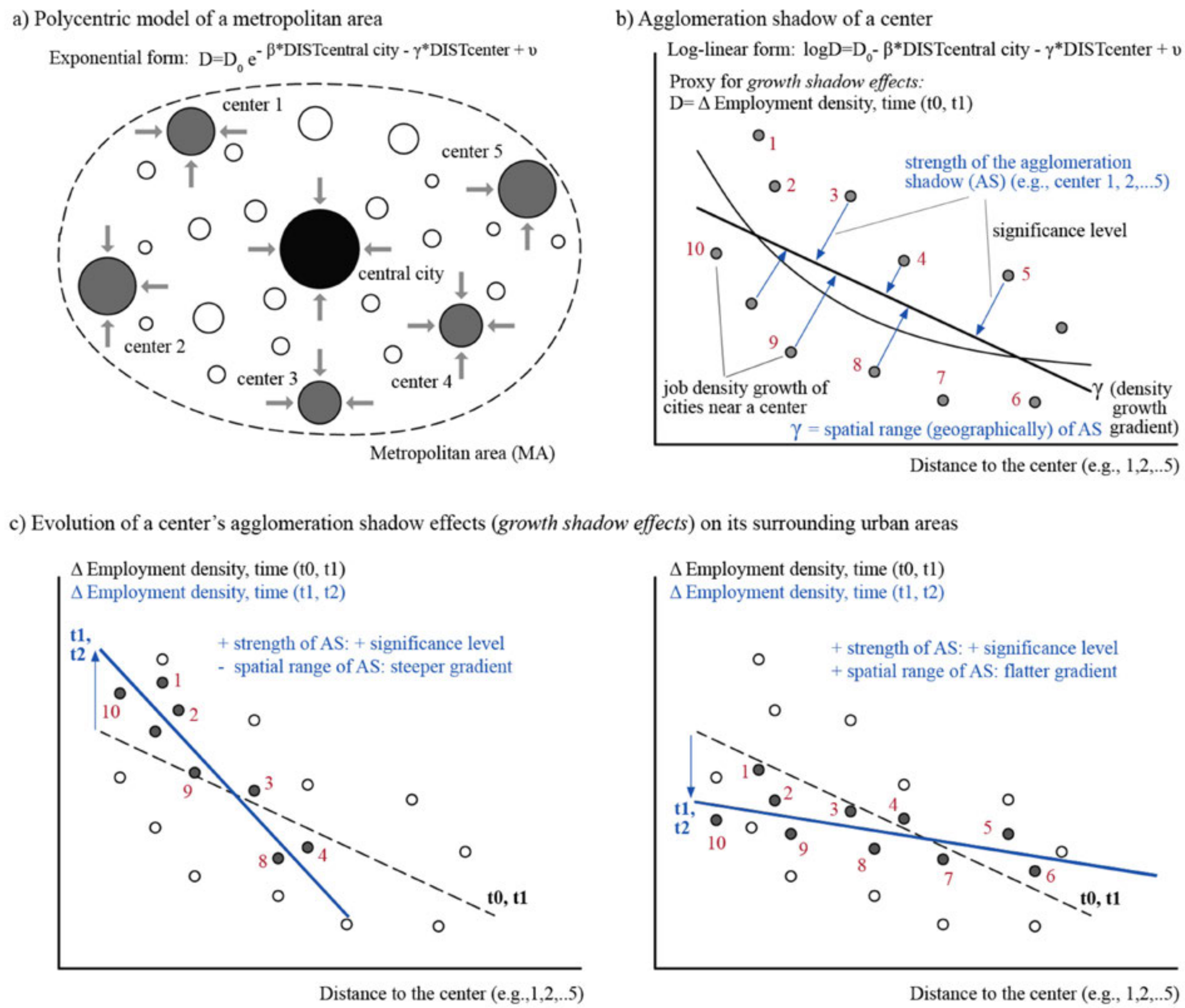


FIGURE 5.1 The polycentric model and agglomeration shadow effects

Note(s): dark gray dots in Figure 5.1c represent cities' growth in employment density near a center (e.g., center 5) at time (t1,t2), whereas white dots represent this growth during the previous period (t0,t1). As can be observed, the growth shadow effect exerted by center 5 on its surrounding urban areas has become stronger because the employment density growth experienced by these surrounding urban areas has become much more dependent on proximity (access) to its agglomeration economies (dots are closer to the linear regression line in the period t1-t2 than in the period t0-t1). The reinforcement of a center's growth shadow effect could therefore imply either a reduction (Figure 5.1c left) or an increment (Figure 5.1c right) of its spatial range.

Finally, although it is perhaps not that uncommon for scholars proposing methodologies to compare their outcomes to those of different methodologies, they generally do not benchmark these outcomes against theoretical predictions to see which method fits best. Here, the comparison with the New Urban Economics and New Economic Geography theoretical frameworks is of the most interest because those frameworks provide the basis for many of the current approaches. In doing so, numerous methodological issues must be considered. A more accurate assessment of the empirical polycentric model must include not only *growth shadow effects* but also a control for 'recursive causality' between factors (e.g., distance to the centers) and the dependent variable (e.g., employment density growth). In addition, the role of transport infrastructure should be considered not only from a static perspective (e.g., distance to the highway) but also from a dynamic one, for instance, to see how changes in infrastructure developments (infrastructure improvements) affect the formation of employment concentrations. Additionally, the issue of spatial autocorrelation must be addressed.

The following section presents a novel method of identifying centers that addresses the issues raised above. Following the urban theories of the New Urban Economics and the New Economic Geography, it uses employment as an indicator of spatial concentration and the spread of agglomeration economies over the metropolitan area. However, this method is based on the use of entropy measures, not density measures.

§ 5.4 A novel method of identifying centers based on entropy measures

Entropy and urban systems

The concept of entropy, which is derived from Shannon's information theory (Shannon, 1948), has been widely used in the spatial complexity theory of urban systems (e.g., Wilson, 1970, 2010). In this study, entropy is used as a measure of the probability that flows can be generated and observed in a spatial unit (e.g., a municipality). Because of entropy's attributes, entropy measures could reveal the degree of concentration, centrality and position in the urban hierarchy of a spatial unit within a geographical system (e.g., metropolitan area) over time. The following example may both explain these attributes and more accurately capture how entropy is defined within urban systems. Here, employment is considered an attribute not only of a metropolitan area but also of each municipality within that metropolitan area. If understood as probability (p_i), the proportion of employment in municipality (i) can be defined as follows:

$$p_i = Emp_i / Emp$$

EQUATION 5.1

where employment (Emp_i) sums up to the total employment of the metropolitan area (Emp), thus implying that all probabilities sum up to 1. Following Shannon (1948:11-16), the quantity of (employment) information 'produced' by (p_i) can be defined as ($1/p_i$), where high employment information appears when the event is unlikely to occur. However, if both this event (probability of finding employment in municipality i) and another event (p_j: probability to find employment in municipality j) occur, the only function that allows the addition of both pieces of employment information ($1/p_i p_j = 1/p_i * 1/p_j$) is the logarithm form (e.g., $\ln 1/p_i$). If the employment information for (i) and (j) is rewritten using the logarithm form, then equation 5.2 is obtained:

$$1/p_i p_j = 1/p_i + 1/p_j - \ln(p_i p_j) = -\ln(p_i) - \ln(p_j)$$

EQUATION 5.2

If we consider all employment probabilities within the metropolitan area, multiply the employment information by the probability of each, and subsequently sum these for (n) municipalities, we obtain the employment Entropy Index (EI) for the entire metropolitan area, which is expressed as equation 5.3:

$$EI = -\sum_{i=1}^{n}(p_i * [\ln(p_i)])$$

EQUATION 5.3

The minimum value of the Entropy Index is 0. This occurs when $P_i=1$ and one municipality (i) dominates the metropolitan area. The maximum value of the Entropy Index is achieved when the probabilities are all equal [Entropy Index=ln(n), so when $p_i=1/n$], leading to a perfectly even spatial distribution of employment across all of a metropolitan area's municipalities. This example shows that the values of the Entropy Index are dependent on two attributes, namely, the distribution of employment and the size of the system, but it may well be that an urban system with fewer elements (n) but a more even distribution has greater entropy than an urban system with more elements.

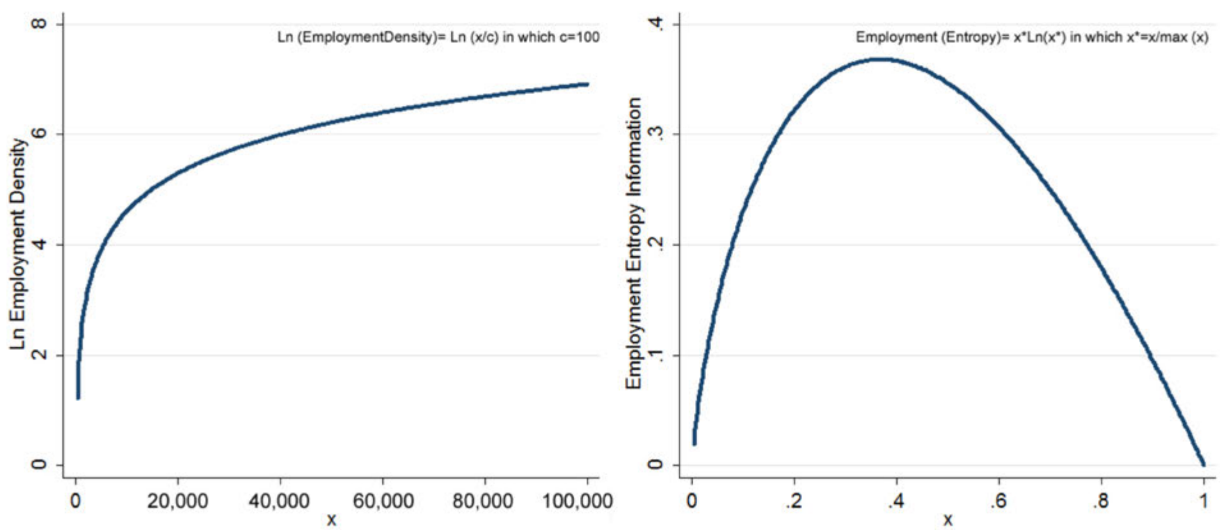


FIGURE 5.2 Maximum of a job function based on density and entropy measures

Note(s): the graph on the left represents an employment density function that is formulated as Ln (EmploymentDensity) = Ln (x/c) in which x represents the number of jobs and c is a measure of land area. The graph on the right displays an employment entropy function, which is formulated as Employment (Entropy) = x Ln (x*) in which x* = x / max (x). To compare both functions of employment, this study lets x range from 0 to 100,000 jobs and supposes a constant measure of land area at 100.*

Furthermore, these two attributes provide entropy measures with a greater ability than density-based measures to accurately capture the concentration/spread of agglomeration economies over a metropolitan area. Although both measures can quantify the extent of spatial concentration in a certain urban area by using a proxy for agglomeration economies (e.g., employment), entropy measures can also relate this spatial concentration to the theoretical maximum spatial concentration achieved in a metropolitan area, given a total number of spatial units and their spatial distribution. This is shown in Figure 5.2, which compares an employment density function with an employment entropy function; it can be observed that the latter function defines a greater maximum value than the former. This observation reveals that entropy measures have two additional main advantages over density measures. First, entropy measures are less sensitive to the spatial unit because they quantify the spatial concentration of each spatial unit relative to the entire system. Thus, entropy measures are not dependent on land area to measure the spatial concentration of agglomeration economies in each spatial unit. This could resolve the issue identified in the preceding section, i.e., that employment density functions that are based on econometric techniques tend to be biased in that they identify 'small' centers (especially those further away from the central city) too easily, even though these centers have a low critical mass of jobs. Second, because entropy measures consider the distribution across spatial units to quantify the each unit's spatial concentration, it is implied that entropy measures can quantify the position of each spatial unit within the spatial distribution and consequently, can indicate each unit's position in the urban hierarchy of the metropolitan area. Therefore, it seems that entropy measures are also capable of considering this rank of spatial units, which the New Economic Geography framework indicates is significant to the nature of agglomeration economies in that an agglomeration shadow may be larger when a center is more important.

Employment entropy and pathways to polycentricity

Figure 5.3 shows how cities' employment entropies can capture the various pathways to polycentricity (decentralization or incorporation/fusion). Imagine a metropolitan area that holds 750,000 jobs, most of which (500,000) are concentrated in a single, dominant city (central city) at time (t). In this case, employment is highly unevenly distributed in this metropolitan area, and the employment Entropy Index consequently tends to 0 rather than Ln(n), thus depicting a monocentric metropolitan structure. Now imagine that between time (t) and (t+2), this metropolitan area has evolved toward a more polycentric configuration.

Decentralization

As explained in section 5.2, the first pathway to polycentricity occurs when the continuing growth of the central city imposes severe agglomeration costs (e.g., congestion, land rents). Coupled with the development of agglomeration economies in certain suburban areas, those costs imply that production and services activities are squeezed out from the central city to those suburban areas, forming centers. This trajectory to polycentricity is translated into entropy measures as follows. The example (Figure 5.3a) shows that the metropolitan structure is clearly monocentric at time (t). Suppose that the central city loses approximately 100,000 jobs (e.g., jobs in advanced producer services and finance, insurance and real estate) in favor of two smaller cities (C3 and C5) between time (t) and time (t+1) that consequently may be considered centers at time (t+2) because of their increased number of jobs. Perhaps these places have become more specialized, which suggests that their localization economies have increased and become attractive to other firms in the same sectors. With their rising prominence as employment centers, these centers (or their surroundings) may also become more attractive places to live because people who work there will realize cost savings in commuting. With more people and more jobs, these centers will provide more agglomeration economies (urbanization economies), making them even more attractive. This would also imply a reorganization of commuting and other trips to access jobs and urban amenities from a focus on a single reference point (central city) to multiple ones. Employment entropy measures capture this transformation to a more polycentric configuration. The scores for individual cities change; those that become more important players in the urban hierarchy receive higher employment entropy scores. For instance, the employment entropy score for C5 almost doubled. The increase in the employment entropy score (from 0.55 at t to 0.88 at t+2) reflects the rise of polycentricity and a more even distribution of employment, which is indicative of a more balanced distribution of agglomeration economies.

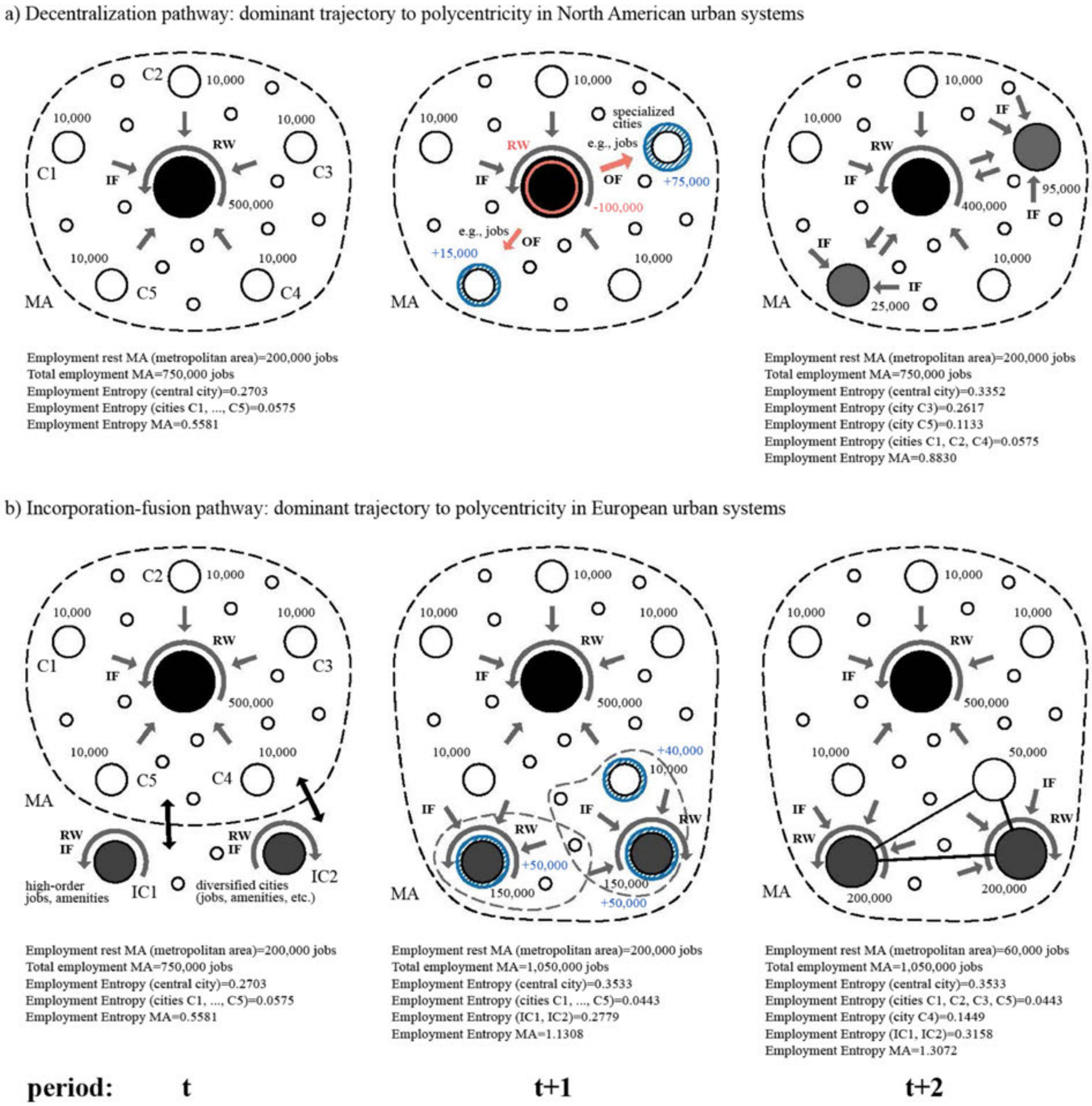


FIGURE 5.3 Conceptualizing the relationships between employment entropy and pathways to polycentricity in metropolitan areas

Note(s): RW stands for Resident Workers, IF stands for In-commuting Flows, and MA represents Metropolitan Area.
Own elaboration building upon Champion's (2001) contributions.

Incorporation-fusion

The alternative pathway to polycentricity, also explained in section 5.2, opens when some independent cities (e.g., IC1 and IC2)—which already have diversified economic structures with relatively high-order amenities and jobs and a capacity to attract non-residential activities—become functionally and spatially integrated into a single metropolitan area for a variety of social, economic and technological reasons, including improved transport links (and lower transportation costs). The boundaries of the metropolitan area at time (t+1) are therefore extended to incorporate these functionally autonomous centers (which are largely self-sufficient in terms of employment, urban facilities, and amenities) that once served distinct labor markets and now cover a wider market together (i.e., through incorporation). It is important to mention that when this pathway to polycentricity involves distinct independent cities of a substantial size (for example, cities that are large enough to be considered separate city-regions), this process is referred to as 'fusion' (see Champion, 2001:664).

To be usable, employment entropy values should be able to reflect this incorporation-fusion process. This process generally implies that agglomeration economies are spread more evenly over the metropolitan area because newly incorporated (or fused) centers (IC1, IC2) have flattened the urban hierarchy and they essentially have strong urbanization economies (150,000 jobs), a self-sufficient labor market (e.g., a large number of resident workers) and (to some extent) their own functional hinterlands. In this regard, entropy measures should capture the flatter urban hierarchy in the metropolitan area that results from incorporation-fusion. Moreover, because of their size and importance, the incorporated-fused centers should generally have higher entropy scores at time (t+2) than centers arising through decentralization had at time (t+2). As indicated above, individual cities and overall employment entropy values in this hypothetical example confirm these urban dynamics (see Figure 5.3b).

Identifying the centers of a polycentric metropolitan area, whether those centers arise out of decentralization or incorporation-fusion, means identifying those cities that have most contributed to uniform employment distribution in a metropolitan area since time (t) and therefore have the highest employment entropy scores at time (t+2). The overall employment entropy score for the metropolitan area could also act as a measure for its degree of polycentricity. However, the aggregate measure of employment entropy is unable to properly distinguish between those centers that have arisen through decentralization and those that have arisen through incorporation-fusion. Centers resulting from decentralization have a high potential to attract workers from all over the metropolitan area, whereas recently incorporated centers still have relatively self-sufficient labor markets (e.g., many resident workers) because of their diversified economic structure and size. Consequently, the disaggregation of the employment entropy measure into resident workers and in-commuting flows, which also takes into account the functional relationships between cities, necessarily seems high to fully account for the various pathways toward polycentricity. In particular, in-commuting flows have been considered as a measure of a city's prestige (e.g., Alderson and Beckfield, 2004) and centrality among a given urban network of cities (e.g., Burger and Meijers, 2012), whereas the number or share of resident workers indicates both the attractiveness of the residential environment and its potential to host non-residential activities such as urban facilities and amenities (Champion, 2001). In these terms, the method of identifying centers proposed in this study based on entropy measures needs to be further developed following the three steps described below.

First step: separating resident workers and in-commuting flows

The first step is to disaggregate the employment entropy measure by measuring entropy based on resident workers (people who live and work in the same place) and in-commuting flows. Both add up to the total employment used for the overall employment entropy measure. To do so, given a matrix of residence-to-work commuting (flows) between municipalities (the spatial unit under analysis of this study), the resident workers' and the in-flows' entropy measures are estimated following the procedure previously explained for the aggregate employment entropy (see equation 5.3)[13].

13 This study uses the Shannon entropy form (equation 5.3). Another form is the evenness entropy form, which normalizes the Shannon form using the logarithm of the number of spatial units within the geographical system under study. The latter allows better cross-country or -metropolitan area comparisons because it obtains comparable entropy measures. This demonstrates that if necessary, entropy measures are adaptable to other geographical contexts to achieve comparable approximations of the level of spatial concentration of agglomeration economies in certain urban areas over the metropolitan area, along with their position in the urban hierarchy. It is also important to note that no local knowledge is required. Here, however, the results are presented for the Shannon form, because only the Barcelona metropolitan region is being studied and there is no need to make comparable entropy measures.

The combination of highest values that result from both employment entropy measures therefore reveals the city that both enjoys the highest level of agglomeration economies and occupies the top spot in the urban hierarchy. It can be assumed that this is still the former central city that dominated the monocentric structure of the metropolitan area before its development (through decentralization and incorporation-fusion processes) into a polycentric configuration.

Second step: identifying positive residuals from employment entropy functions

An important prediction in the New Urban Economics and the New Economic Geography is the attenuation of agglomeration economies with distance from the central city. Therefore, the second step focuses on identifying the positive residuals from the two entropy employment functions (focused on resident workers and in-commuting) using a parametric or a non-parametric model that controls for the distance to the central city. Doing so allows the identification of those urban areas that might enjoy a high level of agglomeration economies at certain distances from the central city. The decision to use either a parametric or a non-parametric model is best made after both models have been tested, following McDonald and Prather (1994) and McMillen (2001b). However, the use of a non-parametric approach requires an additional decision, which demands certain local knowledge to determine the suitable window (e.g., 50%, 95%) of the locally weighted regression. Because it is preferable for this research to use the minimum number of arbitrary choices in the process of identifying centers, it seems most appropriate to use the parametric model.

Consequently, this investigation identifies the positive residuals (above one standard deviation)[14] from two parametric functions: one employing resident workers' entropy measures and the other using in-commuting flows' entropy measures. To do so, this work follows the functional form employed by McDonald and Prather (1994), who state that the negative exponential form is the best. The two employment entropy functions can then be formulated as presented in equations 5.4 and 5.5:

$$RW(EI)_i = \alpha + \delta_1 DCC_i + u_i$$

EQUATION 5.4

$$IF(EI)_i = \alpha + \delta_1 DCC_i + u_i$$

EQUATION 5.5

where $RW(EI)_i$ and $IF(EI)_i$ are the resident workers' and the in-commuting flows' Entropy Index for municipality (i), and (DCC_i) is the distance between the central city and the municipality (i). The results of such an exercise is depicted in Figure 5.4, which also provides a comparison by showing how entropy-based measures differ from density-based measures.

14 The definition of this critical value is related to the size and number of the spatial units under analysis. Studies identifying centers that use positive residues have commonly used a smaller unit (e.g., one-quarter square mile or census tracts) and have determined a critical value that is established at a confidence level of higher than 95%. However, because of the lack of data availability below this scale for the Barcelona metropolitan region, the use of larger spatial units (e.g., municipalities) also tends to reduce the total number of observations and therefore, this criteria leads to identify few centers (between 1 and 3). Next, distinct critical values are tested; this study finds that one standard deviation performs quite well for the Barcelona metropolitan region.

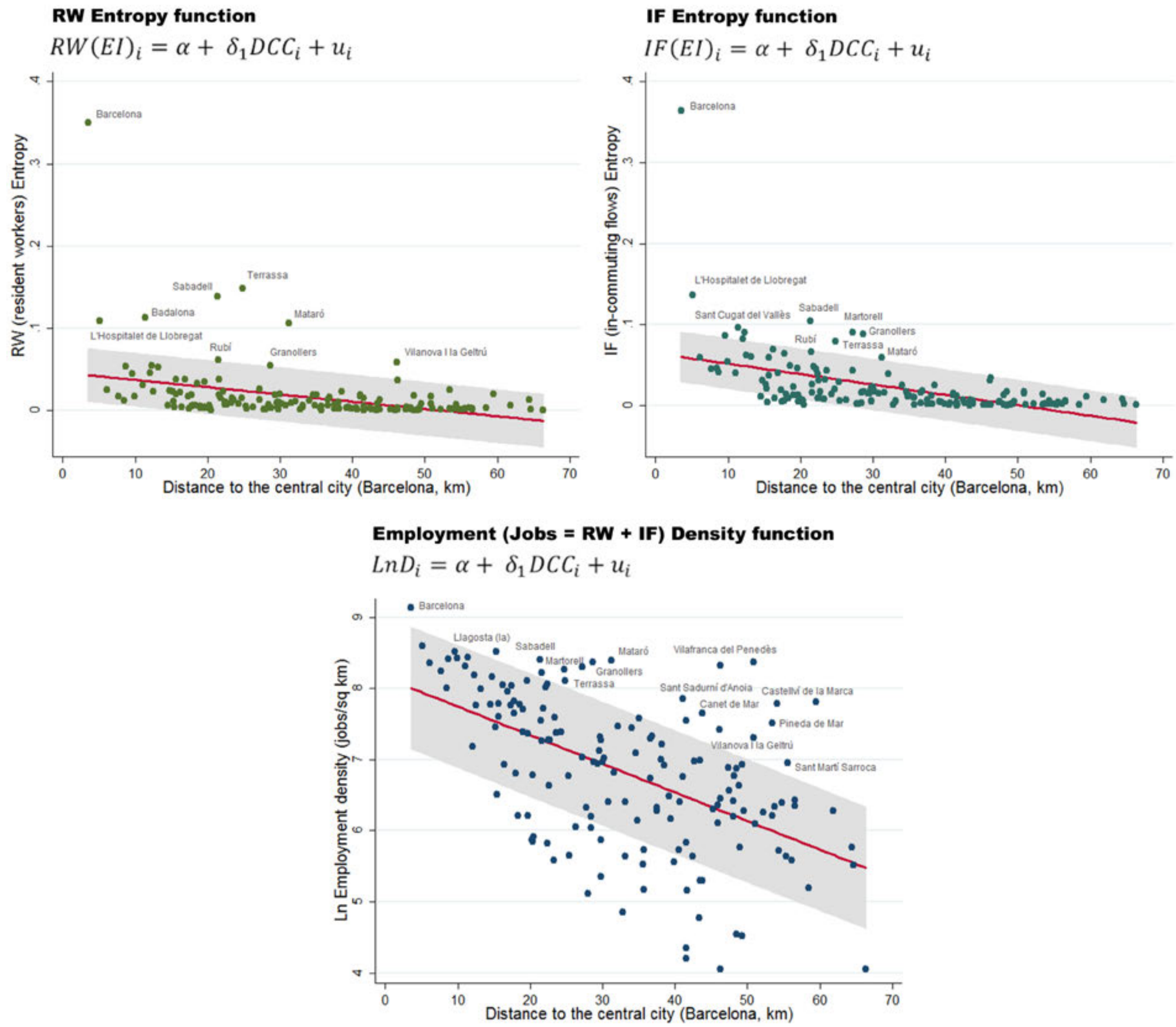


FIGURE 5.4 Two employment entropy functions (resident workers and in-commuting flows entropy functions) versus an aggregate employment density function

Note(s): data comes from 1) the dataset of residence-to-work mobility between municipalities provided by IDESCAT (Institut d'Estadística de Catalunya) for the year 2001, and 2) the dataset of road distances (in kilometers) between Catalonia's municipalities provided by the Catalan government's Department of Territorial Policy and Public Works (DPTOP) for the year 2001. RW stands for Resident Works and IF stands for In-commuting Flows.

As Figure 5.4 shows, the two employment entropy functions make the positive residuals stand out (those municipalities above the shaded area), thus allowing for a straightforward identification of centers with many jobs and showing the existence of the distance-decay effect. Such centers can be found not only close to the central city (e.g., Sant Cugat del Vallès) but also at locations that are more distant. In the previous section, density-based approaches using (non-)parametric methods and even spatial econometric techniques were criticized for too easily identifying small centers at larger distances from the central city even though such center often did not host many jobs. As seen in Figure 5.4, entropy-based measures suffer less from this bias (e.g., they do not identify Sant Martí Sarroca as a potential center). Consequently, my identification method can address the main disadvantage of these three aforementioned approaches. Additionally, unlike the hybrid approach explained in the preceding section, it avoids defining certain thresholds as a second step in the identification process, thus ascertaining that only centers that truly have an important concentration of employment are identified.

Third step: characterizing potential centers following pathways to polycentricity

Finally, the third step makes a further selection of the positive residuals of the two estimated employment entropy functions (equations 5.4 and 5.5) obtained in the previous step. Those municipalities with positive residuals must be considered potential centers. They must be further distinguished according to their development trajectory and—linked to these trajectories—the nature of the agglomeration economies found there. Following the explanations about the interaction between the employment entropies of cities and the pathways to polycentric metropolitan areas, those municipalities with positive residuals according to both the resident workers and in-commuting flow entropy functions can be mainly considered as centers that arise through incorporation-fusion processes. These centers are more associated with the evolution of European urban systems and resemble the model formulations of the New Economic Geography. Centers generally enjoy a high level of agglomeration economies, and urbanization economies might be more substantial than localization economies because of their large population and diversified economic structure. Furthermore, centers are functionally autonomous from the central city and other cities because of their self-sufficiency with respect to employment (with high-order services and jobs) and attractive residential environments. However, they are also functionally autonomous because of their capacity to attract workers from elsewhere (because of their important role and centrality in the network of cities) and will generally have high-order amenities.

Entropy measures also indicate the city's position in the urban hierarchy. Combined with the aforementioned characteristics, it can be argued that these centers cast a larger agglomeration shadow than other centers (e.g., centers resulting from decentralization), leading to a major impact on their hinterlands in the sense that agglomeration shadows are more profound and cover a larger territory. Additionally, it can be argued that their level of agglomeration economies experiences a greater distance-decay effect the further one is from them and therefore, they have a greater impact on the current (empirical) polycentric model suggested by the economics literature. Nevertheless, because these centers have become functionally integrated into the metropolitan area, their impact on their hinterlands might decrease over time because of their increasing interaction with other centers (e.g., the central city), which can be translated into a lower distance-decay effect over time. In many ways, these centers can therefore be labeled as 'high-order', 'large', or even 'mature' centers.

Municipalities that have a positive residual of either resident workers or in-commuting flows entropy can be conceptualized as centers that have arisen through decentralization. In this case, these centers more closely resemble the rise of polycentric configurations in North American urban systems and the theoretical framework of the New Urban Economics. They have a lower level of agglomeration economies than the previous type of centers, and the role played by localization economies is probably more prominent than their urbanization economies because of their specialized economic profile and their relatively limited population size. Compared to 'large' centers, these centers can appear more substitutive of than complementary to the central city because they compete for the same types of economic activities, their formation is more recent, and they are probably located closer to the central city given that they remain somewhat functionally dependent on the central city's high-order urban functions.

This may imply that such centers cast a geographically smaller and less powerful *growth shadow effect* over their surroundings compared to 'large' centers. However, these centers' agglomeration shadows could become more important over time as they begin to be more attractive places to live and concentrate more people and jobs, which in turn will provide more agglomeration economies (urbanization economies). That second type of centers can therefore be denoted 'low-order' or 'emerging' centers.

§ 5.5 Application of the method in Barcelona

Now that the method employed to identify centers has been identified, that method will be applied to the Barcelona metropolitan region. Additionally, we compare that method's results with those achieved by applying two alternative employment density-based methods and another method based on mobility, all of which are explained in section 5.3. First, however, an explanation is given of the data used not only to identify centers but also to evaluate various identification methods.

Data

To identify centers and subsequently evaluate various identification methods, this chapter uses the following datasets. The employment data are derived from census data on the adult (over 16 years of age) population's travel-to-work trips between municipalities in the Barcelona metropolitan region. These municipal commuting flow data are provided by the *Institut d'Estadística de Catalunya* (hereafter, 'IDESCAT') for 1991, 1996, and 2001. The limitation of this mobility data is the lack of information below the municipal level (e.g., by census tract), which meant that the municipality had to be the spatial unit of analysis. This limitation is not uncommon in Europe; data limitations have also forced, e.g., Riguelle et al. (2007), García-López and Muñiz (2007, 2010) and Veneri (2010b), to identify centers on the municipal scale. In addition, it is important to note that although the 2011 census data have recently become available, this census edition has several limitations[15] because of budget cutbacks; consequently, those data do not allow for an exhaustive analysis of inter-municipal commuting.

The calculation of the minimum road distances (in kilometers) between municipalities and the central city and secondary centers is performed by Geographic Information System (hereafter, 'GIS') software using data provided by the Catalan government's Department of Territorial Policy and Public Works (hereafter, 'DPTOP'). The DPTOP also provided the data on highway networks (entrances and exits) and railway networks, including the locations of public-transit stations (train and metro). The calculation of the distances (in kilometers) to the nearest highway entrance/exit and public-transit stations during the period of analysis (1991-2001) was also conducted using GIS software. The built-up area (in square kilometers) used to obtain the net employment density is derived from Corine Land Cover data in 1990 and 2000. The historical land-use data for 1956-2006 are provided by Àrea Metropolitana de Barcelona (hereafter, 'AMB'). More specifically, AMB has transformed information offered by aerial photographs and orthophotos of Barcelona's metropolitan territory into cartographic data for which more than 10 land-use categories (e.g., residential, industrial, etc.) and sub-categories were defined (see AMB 2012:222 for more methodological details). Data on transportation modes (e.g., private and public modes) come from the 2001 Spanish population census elaborated by the *Instituto Nacional de Estadística*. Occupational job data (CCO-94) data at 2 digits of disaggregation is provided by IDESCAT for 1991 and 2001. Annual average wage data for each occupation at the 2-digit level come from the *Estadística d'Estructura Salarial* dataset elaborated by IDESCAT for 2002. Finally, amenities data are obtained from IDESCAT for 2000, 2001 and 2003, depending on the type of amenity (educational, leisure, cultural and sport, health, and social well-being) under consideration.

15 These limitations are related to the fact that the 2011 census did not count the entire population: it was elaborated by defining a survey sample. More specifically, the number of surveys carried out in Catalonia with information about the origin and destination of work trips were 199,480, representing 2.5% of the total population. Moreover, this sample is only available for municipalities of more than 80,000 inhabitants and thus, the aggregate origin-destination matrix can be only constructed for 10 out of 164 municipalities in the Barcelona metropolitan region.

Potential centers (according to the method)

This subsection presents the results of applying the methodology proposed in this study to identify centers between 1991 and 2001 in the Barcelona metropolitan region. The centers identified are presented on the map in the last column of Figure 5.5.

Using the proposed methodology, this study identifies 8 centers in 1991, 5 of which can be considered as 'high-order' or 'large' centers (L´Hospitalet de Llobregat, Badalona, Granollers, Terrassa, and Sabadell) and 3 as 'low-ordered' or 'emerging' centers (Mataró, Vilafranca del Penedès, and Vilanova I la Geltrú). Since 1991, this metropolitan spatial structure has experienced two main transformations, leading to the identification of 12 centers in 2001. First, the process of the emergence of centers has primarily followed the transport infrastructure networks, mostly along the B-30 highway parallel to the coast. Examples of this trend include Martorell (1996), Rubí (1996), and Sant Cugat del Vallès (2001). Second, a reinforcement of the role played by certain centers can be observed over the analyzed period of 10 years. Some centers, such as Rubí and Mataró, have succeeded in developing more powerful agglomeration economies since 1991, leading to their being considered 'large' centers in 2001. In both processes, post-1991 improvement in infrastructure transport (see Appendix 5.1)—which primarily aimed to increase connectivity and accessibility both along the coast and between the central city and its surrounding urban areas—could also have exerted a considerable influence. For example, increased connectivity and accessibility seemed to have facilitated job decentralization from the central city to close-by areas, leading to the rise of 'emerging' centers such as Cornellà de Llobregat (1996), El Prat de Llobregat (2001), and Sant Cugat del Vallès (2001).

Comparison of the outcomes of various methods of identifying centers

Figure 5.5 also presents the outcomes of alternative methods, allowing for a comparison of existing methods with my novel method. These alternative methods include the use of certain employment thresholds, as proposed by Giuliano and Small (1991), but using the thresholds suggested by García-López and Muñiz (2007, 2010)[16] as relevant for the Barcelona case. A second method of comparison is the parametric method of identifying peaks of employment density at certain distances from the central city, following McDonald and Prather (1994). A third method is the mobility-based method, which has also been previously applied to Barcelona. This study uses the centers identified by Masip and Roca (2012), who follow the approach of Roca et al. (2009) based on identifying centers and delimiting metropolitan areas by examining the functional links between cities.

Considering the other two density-based methods, this research identifies 18 (+3 since 1991) and 11 (+1 since 1991) centers in 2001, following the methods of McDonald and Prather and García-Lopez and Muñiz, respectively. In contrast, Masip and Roca's study illustrates the existence of 24 (+8 since 1991) mobility-based centers in 2001. In addition, as shown in Figure 5.5, the differences between the centers identified by the novel entropy-based method and those identified by the job threshold-based method are less significant than the differences between the centers identified by the job density-based function and the centers identified by the mobility-based approach. Essentially, the entropy-based method proposed in this study seems to be able to identify both centers that are close to the central

16 This study has replicated García-López and Muñiz's method of using net job density instead of gross job density to address the biased estimation that may appear in the identification of centers when gross job density is used. Gross density is highly dependent on the legal boundaries of the municipalities. This may entail that although a municipality has considerable employment, it is not identified as a center because the 'authority' surface defined by its administrative boundaries is also very large. This cannot occur if the net employment density is used, because artificialized areas can properly measure the portion of land that is specifically used for economic activities, not the total surface of the municipality, which also includes open spaces, highways and roads, construction sites, etc.

city (e.g., L'Hospitalet de Llobregat, El Prat de Llobregat, Badalona, and Cornellà de Llobregat), as the employment threshold-based approach does, and centers that are too far from the central city (e.g., Vilanova I la Geltrú), as the employment density-based function or the flow-based method does.

That notwithstanding, neither the two density-based methods nor the mobility-based approach identify the centers of Sant Cugat del Vallès and Rubí. This omission is important first because these cities have been highlighted as new centers by the spatial plans of the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona,* the 1995 *Pla Territorial General de Catalunya*, and the *1998 Pla Territorial Metropolità de Barcelona* (provisional proposal) explained in chapter 3. Second, this omission is relevant because these two cities, which are located in the region of Vallès Occidental, have played a role in revealing discrepancies between the polycentric model proposed by the 2010 Barcelona Metropolitan Territorial Plan and the recent urban developments on the ground, as revealed in chapter 4. Therefore, the polycentric structure resulting from the use of the entropy-based method could reinforce the doubts about whether the polycentric model of the Barcelona Metropolitan Territorial Plan based on the seven cities of the *Arc Metropolità* (Metropolitan Arch) is the most convenient for the Barcelona metropolitan region.

More specifically, whereas the entropy-based method identifies the cities of Mataró, Granollers, Sabadell, Terrassa, and Vilanova I la Geltrú as centers, consistent with the polycentric territorial model of the Barcelona Metropolitan Territorial Plan, it also shows that the Vilafranca del Penedès (a city of the Metropolitan Arch) is not considered a center. However, it identifies the cities of Sant Cugat del Vallès, Rubí, Badalona, L'Hospitalet de Llobregat, Cornellà de Llobregat, and El Prat de Llobregat as centers in the Barcelona metropolitan region.

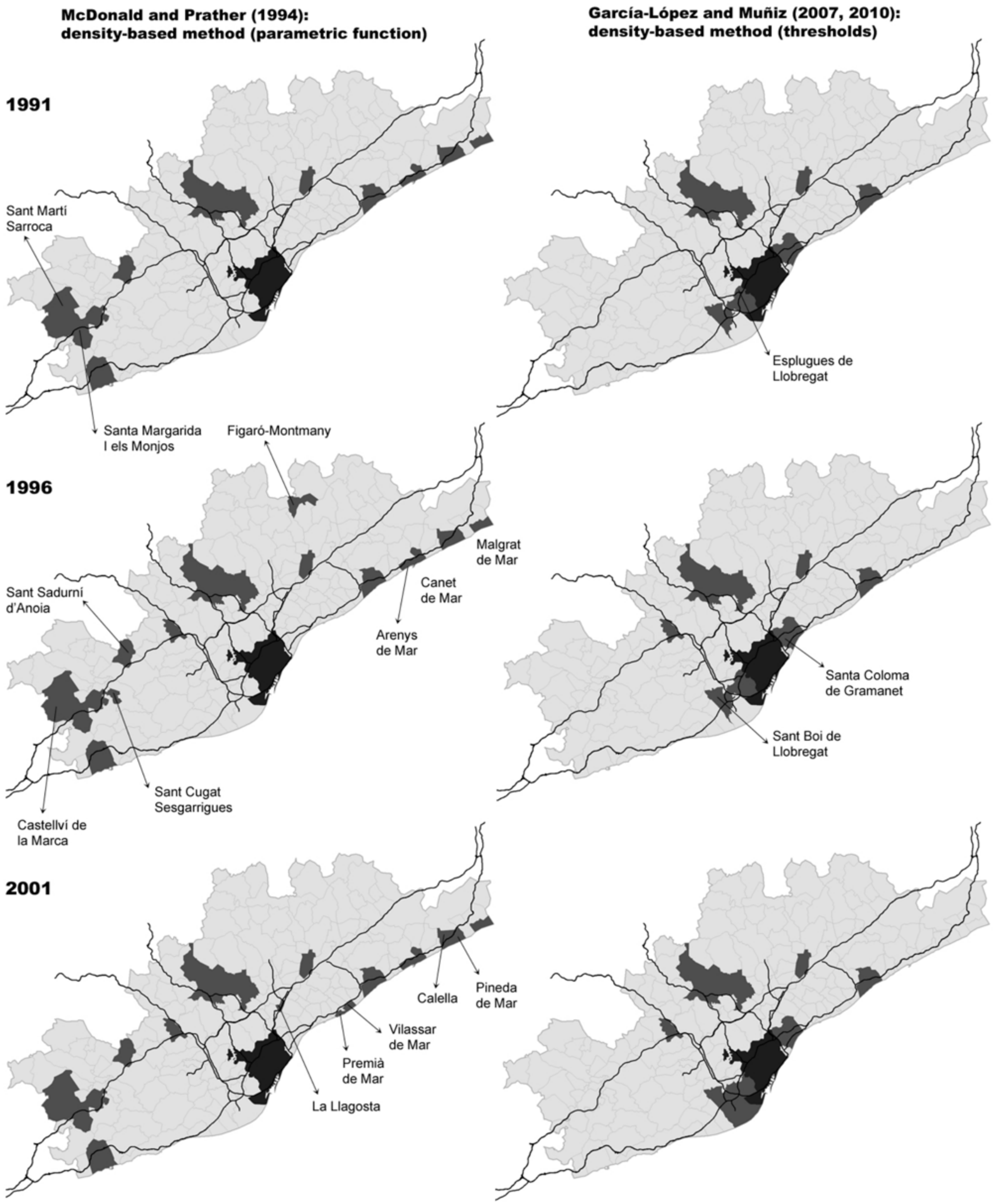
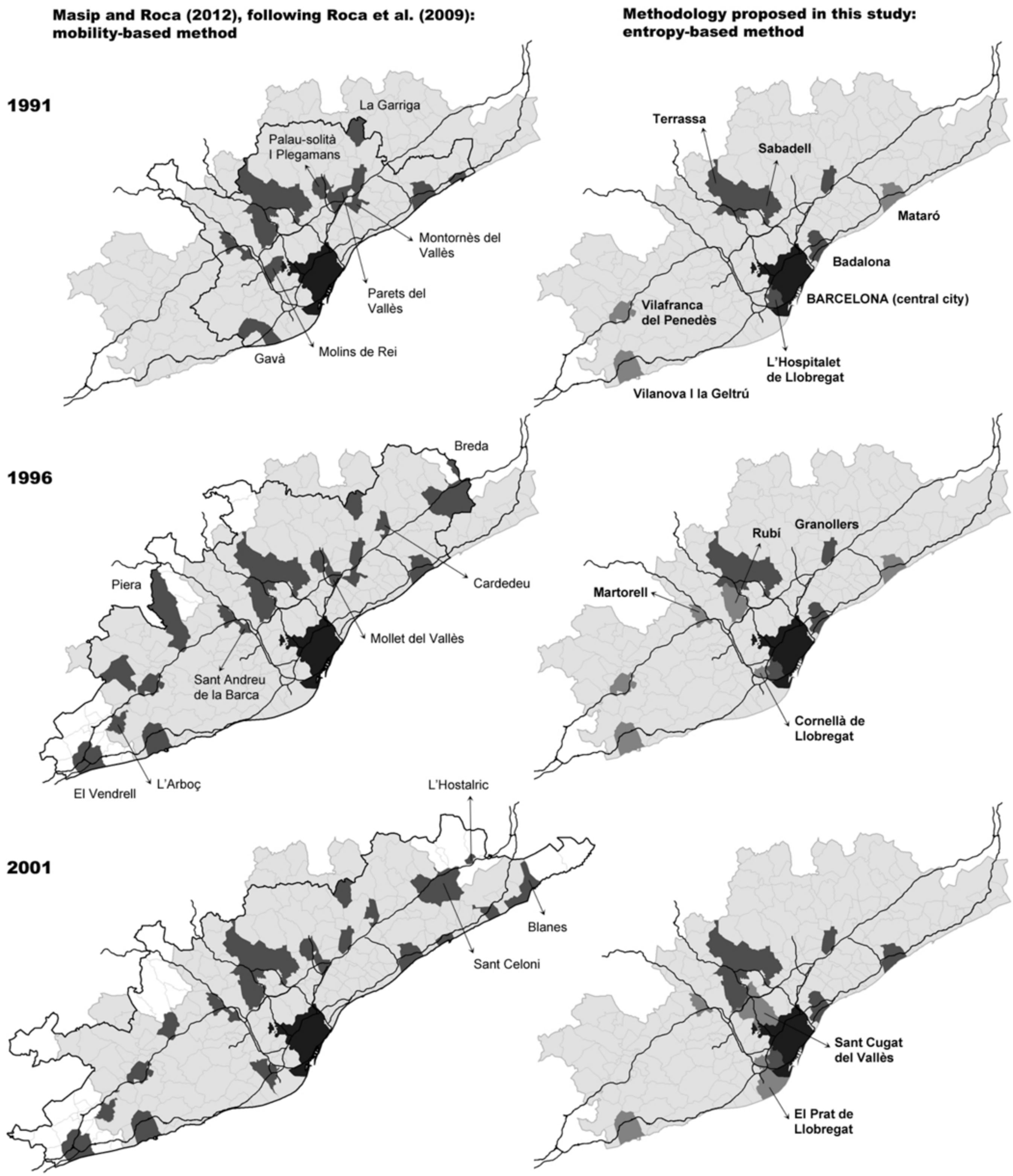


FIGURE 5.5 Potential centers in Barcelona: entropy-based method versus alternative, well-known identification methods

Note(s): 1) the thick, dark outline represents the functional boundaries of the Barcelona metropolitan region that is delimited following Roca et al. (2009), 2) the light gray color filled in for some municipalities defines the administrative boundaries of the Barcelona metropolitan region, and 3) with respect to the centers identified by the method proposed in this study, dark gray represents the 'high-order' or 'large' centers, whereas light grey represents the 'low-order' or 'emerging' centers.



Masip and Roca (2012), following Roca et al. (2009): mobility-based method
Methodology proposed in this study: entropy-based method
1991
La Garriga
Palau-solità I Plegamans
Montornès del Vallès
Parets del Vallès
Molins de Rei
Gavà
Terrassa
Sabadell
Mataró
Badalona
BARCELONA (central city)
Vilafranca del Penedès
L'Hospitalet de Llobregat
Vilanova I la Geltrú
1996
Breda
Cardedeu
Piera
Mollet del Vallès
Sant Andreu de la Barca
L'Arboç
El Vendrell
Granollers
Rubí
Martorell
Cornellà de Llobregat
2001
L'Hostalric
Blanes
Sant Celoni
Sant Cugat del Vallès
El Prat de Llobregat

§ 5.6 Evaluation of various methods of identifying centers

The question remains whether the novel entropy-based method identifies the centers of the Barcelona metropolitan region more accurately than existing methods, including the current approach of the 2010 Barcelona Metropolitan Territorial Plan. The remainder of this chapter is devoted to answering that question. Two evaluation approaches are applied. The first approach is rather straightforward and entails a comparison of the outcomes of the novel method with actual urban development on the ground, thereby focusing on those outcomes that are different from other methods. The novel method should be able to correctly detect emerging centers in which substantial urban development has occurred. To do so, we explore both the location of recent urban projects since 1991 and the transformation of land use since 1956. The second approach is more strongly rooted in the economics literature and adopts the perspective that the most accurate method is the one that is the most consistent with the (empirical) polycentric model. An econometric modeling framework is built and applied to explore this approach in a manner that compares all of the different methods. The first approach will be discussed in this section, and the second approach is the subject of sections 5.7 and 5.8.

Outcomes of the novel method versus recent urban development projects

Figure 5.6 presents the post-1991 urban development projects located beyond the central city of Barcelona. The main conclusion of the study of the location of recent urban development projects is that the method proposed in this study can identify as centers those places beyond the city of Barcelona that were the locations of the main urban development projects. These places did experience an increase in employment, urban facilities and amenities. This increase can be illustrated by three examples, which include those centers that are identified by the novel method but not (in general) by the other methods.

First, my entropy-based method identified the center of El Prat del Llobregat in 2001, which was not previous detected. Indeed, this place has experienced important urban development, such as two logistics projects bringing 9,000 jobs (ZAL II and the logistic activities terminal) and two urban extension projects bringing approximately 10,000 jobs. One of those projects is linked to the airport of Barcelona and labeled the 'airport city center'; another, El Prat Nord, aimed to extend the city center of El Prat de Llobregat beyond its current urban grid.

Second, the method proposed in this study identifies the cities of L'Hospitalet de Llobregat and Cornellà de Llobregat as centers. The former city developed an ambitious urban project known as 'Business district Gran Via'. This urban project created an estimated 12,100 jobs because of its concentration of front-office functions and high-order amenities in a strategic location close to the central city of Barcelona. Cornellà de Llobregat developed the 'Technological Park WTC' and constructed 'Sport City F.C. Espanyol', an important sporting amenity with commercial and service activities.

Third, the novel method proposed here also identified the cities of Rubí and Sant Cugat del Vallès as centers. These cities, together with others located along the B-30 infrastructure corridor, experienced a concentration of technological-business parks, universities and institutions of higher education that is referred to as the 'Catalonia Innovation Triangle (CiT)'.

A1 El Prat de Llobregat. ZAL II (Logistic activities zones) (2004): 705,830 GFA and 5,880 jobs & Logistic activities terminal (2004): 144,200 GFA and 3,000 jobs

Source: www.barcelonalogistic.com.

A2 El Prat de Llobregat. Airport city center (2005): 240,000 GFA and 6,980 jobs

Source: © Antonio Font (2003).

A3 El Prat de Llobregat. El Prat Nord (2005): 228,970 GFA and 3,020 jobs

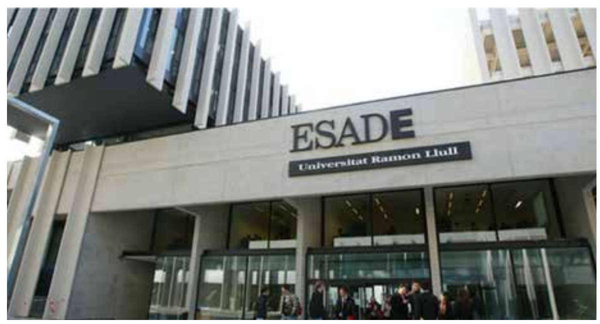
Source: Kees Kaan and Jaume Carné (2010).

B1 Rubí – Sant Cugat del Vallès. Catalonia Innovation Triangle (CiT) along B-30 infrastructure corridor

Source: www.cit.cat.

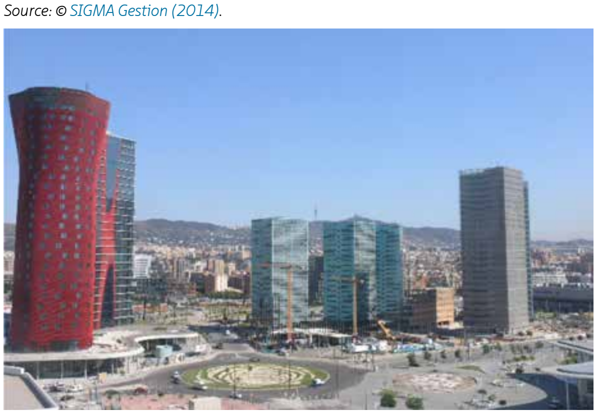
B2.1 Rubí – Sant Cugat del Vallès. Technological and Business Parks

Source: © SIGMA Gestion (2014).



B2.2 Rubí – Sant Cugat del Vallès. Universities and Institutions of Higher Education

Source: © Esade Business & Law School (2010).



C L'Hospitalet de Llobregat. Business district Gran Via L'Hospitalet de Llobregat (2002): 305,300 GFA and 12,100 jobs

Source: www.consorcigvhospitalet.com.

D Cornellà de Llobregat. Technological Park WTC (2001): 52,570 GFA and 2,100 jobs & Sport City F.C. Espanyol (2006): 55,000 GFA and 1,980 jobs

Source: © Michael Kreuz (2013).

FIGURE 5.6 Centers identified by the entropy-based method and main recent urban development projects located beyond Barcelona

Note(s): GFA stands for Gross Floor Area.

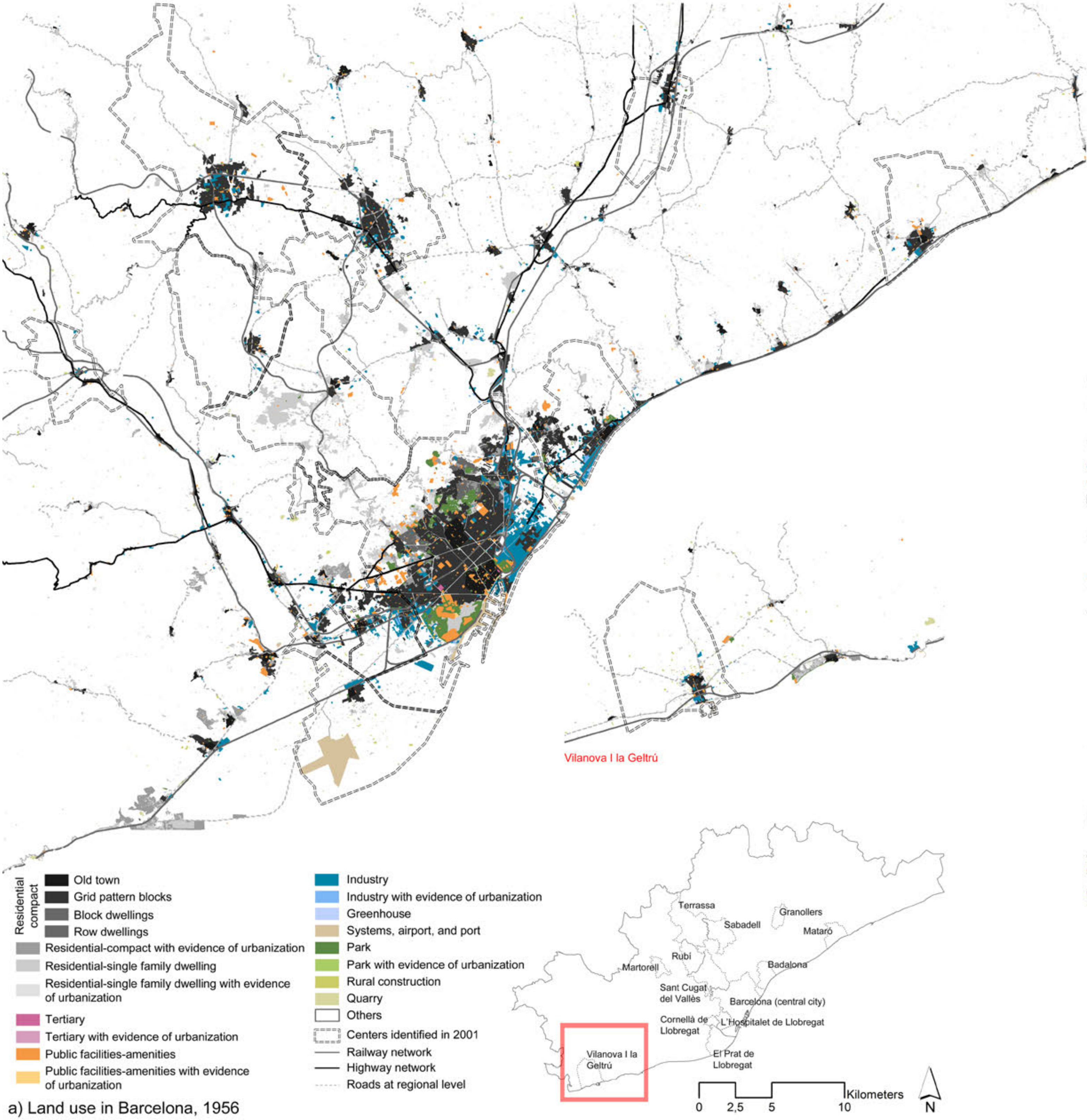
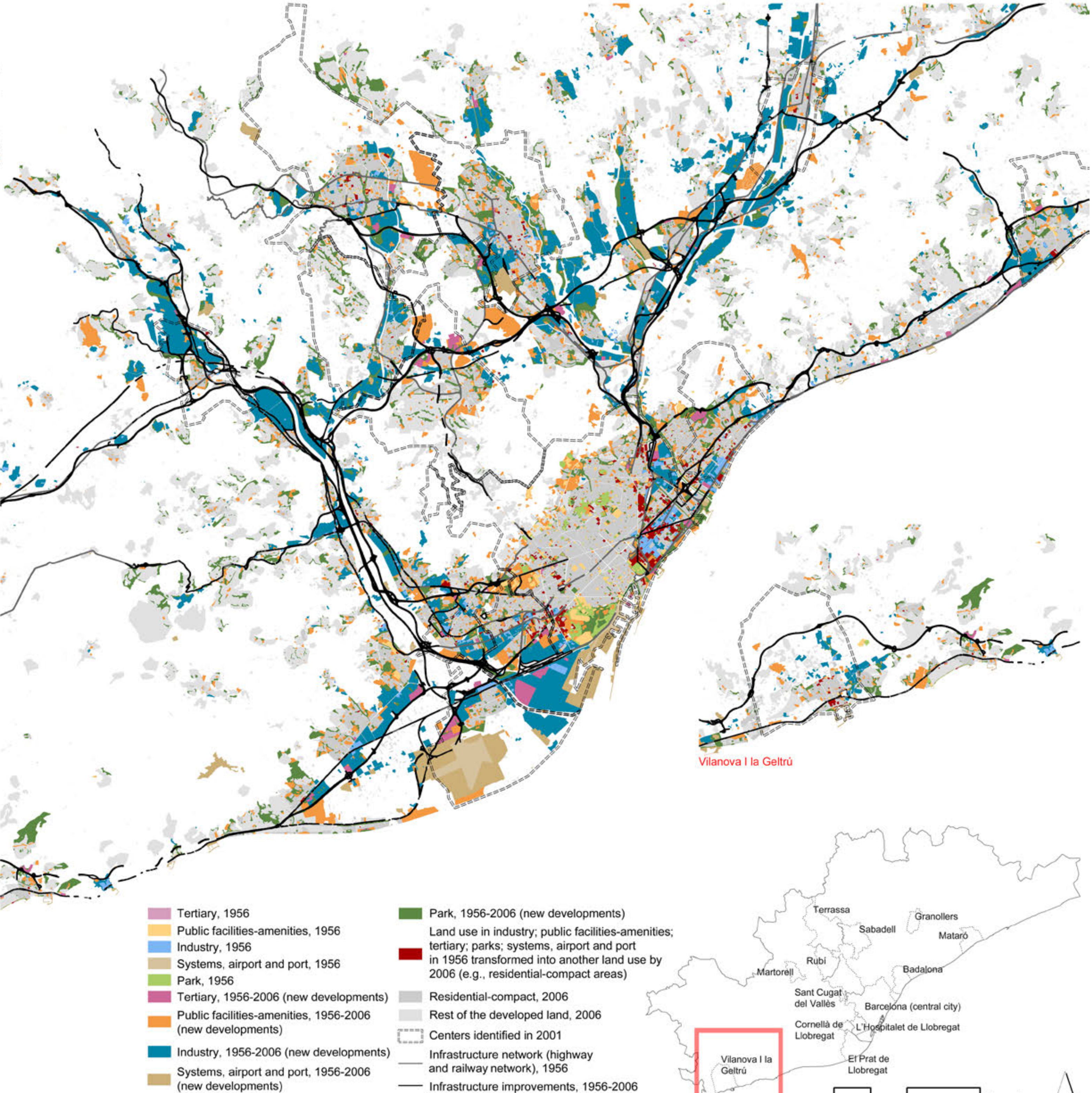


FIGURE 5.7 Historical land-use development in the Barcelona metropolitan region, 1956-2006

Source: own elaboration based on historical land use data provided by AMB (Àrea Metropolitana de Barcelona).



b) Development of land use in Barcelona, 1956-2006

Outcomes of the novel method versus historical land-use development in Barcelona, 1956-2006

This subsection compares historical land-use development since 1956 (see Figure 5.7) in the Barcelona metropolitan region with the centers identified by the novel method for the 1991-2001 period. Two interesting observations can be made based on Figure 5.7. First, urban centers that were already important (given their urban mass and industries) in 1956 are identified by the novel method (Sabadell and Terrassa), which also identifies the other main industrial settlements that were independent from the central city in 1956 as centers (Granollers, Mataró and Vilanova I la Geltrú). It is important to note that these five cities also contained a large part of the land beyond Barcelona where public facilities and amenities were concentrated. The presence of such functions may indicate those cities' relative independence (in functional terms) from Barcelona (Figure 5.7a).

Second, the entropy-based method can adequately capture trends with respect to the spread of industrial and tertiary activities and public facilities-amenities throughout the metropolitan territory, which have been coupled with the development of small urban entities into new centers since 1956 (Figure 5.7b). For instance, these trends involve centers that have arisen through decentralization—for example, Martorell and Sant Cugat del Vallès. These were relatively less-populated cities that had no particularly strong industrial profile in 1956. However, they have become increasingly important as they have concentrated not only compact residential extensions and public facilities-amenities linked to their old town but also industrial developments and tertiary activities linked to new transportation infrastructures. Consequently, it seems that the centers identified by the entropy-based method could represent land-use transformations in the Barcelona metropolitan region. There is a strong association between the centers identified and the transformation of land to urban uses, and it is clear that the centers identified as 'large' or 'high-order' were those that were already important, whereas the centers identified as 'emerging' or 'low-order' were those that had experienced rapid new development.

§ 5.7 Empirical framework for evaluating the polycentric model

Criteria for evaluating methods

This section builds an empirical framework for assessing the outcomes of the various identification methods (visualized in Figure 5.5) to evaluate which set of identified centers appears to be the most accurate to define the polycentric model in Barcelona. The definition of 'most accurate' rests on two criteria, both grounded in the New Urban Economics and New Economic Geography literature on the theories about the formation of centers and the empirical framework to test the existence of a polycentric model in metropolitan areas. Additionally, this section utilizes the concept of 'agglomeration shadows', i.e., the idea that cities cast a shadow over their surroundings. Although this concept might sound negative ('shadow')—which in some ways is because the area over which this shadow is cast experiences competition over time from centers—it also means that people and firms in this area will generally have access to their agglomeration economies. Agglomeration shadows have two properties: their spatial range (geographically) and their degree (how powerful they are). These properties can be graphically represented as a center's distance-decay effect over time (recall Figure 5.1). Thus, the first criterion is that a method should identify the centers with the highest level of agglomeration economies as reflected in a more substantial, significant decrease of employment density with distance from those centers, i.e., their density gradient and its significance level. The second criterion is that a method should identify the centers that cast the most severe agglomeration shadows as reflected in a more substantial, significant decrease of employment density growth with distance from those centers, i.e., their density growth gradient and its significance level. Higher-ranked centers—for example, the central city of the metropolitan area and the centers arising out of incorporation-fusion—are likely to cast more severe agglomeration shadows in that they are deeper and cover larger territories. As noted, the comparison in this section will focus on the method based on measuring entropy that is proposed in this chapter, the two alternative employment density-based methods and the method based on flows, along with the centers proposed by the 2010 Barcelona Metropolitan Territorial Plan.

Empirical implementation: estimation strategy and variables

To build this model framework, this study departs from the most common function to estimate a polycentric model. This model has been used by McDonald and Prather (1994), McMillen and McDonald (1997, 1998a, 1998b), and McMillen and Lester (2003) and is formulated as follows:

$$LnD_i = \alpha + \delta_1 DCC_i + \delta_2 DOC_i^{-1} + \boldsymbol{\beta_3 X}_i + u_i$$

EQUATION 5.6

Following the aforementioned works, equation 5.6 can be estimated using Ordinary Least Squares (hereafter, 'OLS') techniques. (D_i) stands for the job density in a municipality (i), (α) is the estimated employment density in the central city, (DCC_i) represents the distance from the central city, (δ_1) is its associated density gradient, (DOC^{-1}_i) is the inverse of the distance to the nearest secondary center[17], (δ_2) is its corresponding density gradient, ($\mathbf{X}_i$) is a vector of the remaining explanatory variables that indicate proximity either to various locations (e.g., train station, highways, airports, coasts, etc.) or to urban attributes that are also expected to affect densities (e.g., urban amenities and presence of highly educated workers), and (u_i) is the error term.

Based on the data available for the Barcelona metropolitan region, the vector ($\mathbf{X}_i$) refers to the following variables: (1) initial conditions of density level, (2) distance to the nearest public-transit station, (3) distance to the nearest highway, (4) distance to the coast, (5) the presence of non-motorized transport[18], (6) average trip distance of commuters in relation to their places of residence[19], (7) concentration of the most highly paid occupations[20], and (8) presence of urban amenities[21]. Although the interpretation of the coefficient of the distance to the central city can be

17 The use of an inverted distance eliminates problems of multicollinearity (McDonald and Prather, 1994). For this reason—and following the studies of McMillen and McDonald (1998) and McMillen and Lester (2003), among others—this study uses a single variable that takes the inverted distance to the nearest secondary center. More specifically, using this variable instead of alternatives such as the distance to each secondary center mitigates the multicollinearity issue derived from estimating individual gradients for physically adjoining centers (e.g., Sant Cugat del Vallès, Rubí, and Terrassa).

18 This determinant is calculated as follows: $NoMot\_share_i = \frac{\sum_{i,j} NoMot_{ij}}{\sum_{i,j} f_{ij}}$, where $\sum_{i,j} NoMot_{ij}$ are the number of trips made by non-motorized transport (e.g., walking and, cycling) by the REP (resident employed population, $REP = \sum_{i,j} f_{ij}$) in a given municipality (i), respectively.

19 This explanatory variable is computed as follows: $ATD_{residence,i} = \frac{\sum_{i,j} f_{ij} * d_{ij}}{\sum_{i,j} f_{ij}}$, where ($f_{ij}$) are the number of workers moving from municipality (i) to municipality (j), (d_{ij}) are the distances between (i) and (j), and $\sum_{i,j} f_{ij}$ are the total resident employed population (REP) of municipality (i).

20 To calculate the concentration of best-paid occupations for each municipality (i), this research first defines those occupations with an average annual wage of above the 90th percentile for the total sample of occupations. Second, this study computes the location quotient (LQ) of this group of occupations for each municipality (i) in the metropolitan area.

21 The presence of amenities is calculated using a normalized score index that ranges from a minimum value of 0 to a maximum of 100. To perform that calculation, this study has considered four distinct groups of amenities: (i) social well-being, (ii) health, (iii) leisure, cultural and sport and (iv) educational.

obtained directly, the interpretation of the estimated coefficient of the inverse of the distance to the nearest secondary center cannot. For example, a positive (negative) coefficient indicates that job density, which proxies the degree of agglomeration economies, decreases (increases) as the distance to the nearest secondary center increases. However, equation 5.6 also cannot take into account if centers cast agglomeration shadows over their urban surroundings or the role played by infrastructure improvements in the rise of agglomeration economies in certain urban areas. To address these two issues, equation 5.6 is reformulated into equation 5.7:

$$LnY_i = \alpha + \delta_1 DCC_i + \delta_2 DOC_i^{-1} + \delta_3 \Delta Dhwy_i + \boldsymbol{\beta_4 X_i} + u_i$$

EQUATION 5.7

(Y_i) stands for job density in a municipality (i) at certain time (D_i) or employment density growth in a municipality over period (ΔD_i), and ($\Delta Dhwy_i$) quantifies the changes in distance to the nearest highway entrance/exit in a municipality (i), which proxies for transportation infrastructure improvements (see Appendix 5.1) between time (t) and time (t+1). In this manner, adding employment growth density as a dependent variable allows this study to consider the *growth shadow effects* from centers in a manner similar to that of Partridge et al. (2009a), who have tested these effects with respect to population growth. Moreover, inclusion of the effect of highway improvements enables this research to examine whether job density spreads out along new highways and increases in urban areas that became more accessible, much like Baum-Snow (2007), García-López (2012) and Baum-Snow et al. (2013) have previously studied such effects in the context of population suburbanization.

Coping with spatial autocorrelation

Although the estimation strategy represented by equation 5.6 was set forth in García-López and Muñiz (2007, 2010) and Sun et al. (2012), among others, other studies such those of McMillen (2004) have suggested that using OLS techniques for the estimation can lead to inconsistent results because of the presence of spatial autocorrelation arising out of the spatial dependence between observations related to the dependent variable and those associated with the error term. To address this issue and detect the appropriate form of spatial autocorrelation, this study followed the estimation strategy framework described by Anselin et al. (1996), which provides methods of discriminating between a spatial lag model and a spatial error model using the OLS residuals. More specifically, that study suggests Lagrange multiplier tests (LMLAG and LMERR) and their robust versions (R-LMLAG and R-LMERR) to choose the most appropriate spatial autocorrelation model. The rule proposed is based on considering the extent to which the significance levels of these four Lagrange multiplier tests differ from each other. For example, when LMERR is more significant than LMLAG, and R-LMERR is significant but R-LMLAG is not, then the appropriate model to consider is the spatial error model. The spatial lag model is therefore a more appropriate model when LMLAG and its robust version (R-LMLAG) are significant, whereas LMERR and R-LMERR are less or not significant. Applying these tests and criteria to equation 5.7 for all models, considering the four different identification methods and the Barcelona Metropolitan Territorial Plan's territorial model (see further results in Table 5.2-5.3), this study concludes that Spatial Error (hereafter, 'SE') models are preferable to Spatial Lag (hereafter, 'SL') models. Therefore, this research departs from equation 5.7 to implement a SE model, as shown in equations 5.8 and 5.9 show:

$$LnY_i = \alpha + \delta_1 DCC_i + \delta_2 DOC_i^{-1} + \delta_3 \Delta Dhwy_i + \boldsymbol{\beta_4 X_i} + \boldsymbol{u_w}$$

EQUATION 5.8

$$\boldsymbol{u_w} = \lambda \boldsymbol{W} u + \boldsymbol{\xi}$$

EQUATION 5.9

where ($\mathbf{u}_w$) is the vector of error terms, spatially weighted using the weights matrix (**W**), (λ) is the spatial error coefficient (autoregressive parameter) of a spatial error model, (**ξ**) is a vector of uncorrelated error terms, and where after performing a sensitivity analysis of the weights matrix (**W**), a queen-standardized weight—not a rook- or a distance-standardized weight—is implemented.

Coping with endogeneity

Another estimation issue may also arise. The use of OLS and SE models may not account for the simultaneity of urban spatial structure, improvements in transport infrastructure and employment density and growth in employment density. In the previous model specifications (equations 5.7-5.9), it is assumed that spatial structure and transport infrastructure improvements have a direct effect on both employment density and employment density growth. However, the direction of these causality relationships might be quite unclear. As Baum-Snow (2007) has noted, and as confirmed by García-López (2012) and Baum-Snow et al. (2013), among other studies, infrastructure improvements are endogenous to population density growth because the location of highway networks is not random in the territory. Therefore, it can be expected that transportation improvements may also be endogenous to both employment density and employment density growth. That would mean that infrastructure improvements might be associated with numerous benefits for firms (e.g., increasing accessibility), which might lead to higher employment concentration in certain areas. That said, causality might also run in the other direction when policymakers and (local and regional) public administrations wish to promote the connection between high (and predicted) employment density areas.

There are no previous studies of recursive causality related to the spatial structure variables in the empirical evaluation of the polycentric model. This causality may be conceptualized as follows. Causality might run from centers that form the polycentric structure to employment densities because agglomerations are associated with benefits to firms such as labor-market pooling, access to intermediate goods, knowledge spillovers, and proximity to consumers (Rosenthal and Strange, 2004), which in turn could augment both centers' job densities and their *growth shadow effects* on their local hinterlands. However, causality might also run in the other direction, albeit in a manner similar to that described above, when planners and urban developers may want to promote new centers or serve cities with poor employment densities, urban facilities, etc., by establishing regulations that concentrate and steer new urban development in a compact way.

The failure to address these two recursive causalities may lead to biased estimation results because the independent variable might be correlated with the error term of the dependent variable. In this respect, the econometric literature has commonly suggested the use of Two-Stage Least Squares (hereafter, 'TSLS') estimation to address this issue. This requires the estimation of one equation for each endogenous variable using instrumental variables in the first stage and another equation to predict the effect of those endogenous variables on the dependent variable in the second stage. The second stage of the TSLS estimation is formulated as follows:

$$LnY_i = \alpha + \delta_1 \widehat{DCC_i} + \delta_2 \widehat{DOC_i^{-1}} + \delta_3 \Delta\widehat{Dhwy_i} + \boldsymbol{\beta_4 X_i} + u_i$$

EQUATION 5.10

$(\widehat{DCC_i})$, $(\widehat{DOC_i^{-1}})$ and $(\Delta\widehat{Dhwy_i})$ are predicted changes in distance to the central city, the inverse of the distance to the nearest secondary center, and infrastructure improvements as estimated in the first stage of TSLS estimation using instrumental variables (H_i). For this, it is necessary to use appropriate instrumental variables that are correlated with the endogenous independent variables but not with the dependent variable. Thus, the instruments need to fulfill two general conditions: they should be both relevant (not weak) and exogenous (valid). Based on data availability for the Barcelona metropolitan region, this study intends to construct a set of instrumental variables that are not related to job density and job density growth today, but that made significant contributions to today's distance to the central city, the inverse of the distance to the nearest secondary center, and infrastructure improvements. These variables are as follows: 1) past concentration of population (population density in 1857, 1877, 1900, 1910, 1920, 1930, and 1940); 2) past concentration of human capital (i.e., the non-illiterate population for those historical years); 3) historical infrastructure developments in Catalonia, which are reported in Appendix 5.2, including roads (distance to the Roman roads, 1760 postal roads, half of the 19th-century main roads, and half of the 20th-century main roads) and the railroad network (distance to the railroad network in 1860, 1880, 1900, 1923, and 1935); and 4) historical land use profile (proportion of industrial, tertiary and public facilities-amenities land relative to the total built-up land in 1956)[22].

To test the hypothesis of endogeneity along with the relevance and validity of the instruments, this study performs a set of statistical tests. The independent endogenous variables are tested both separately and simultaneously. That means that this work runs three regressions in which the distance to the central city, the inverse of the distance to the nearest secondary center, or the infrastructure improvements are instrumented, and one regression in which these three endogenous regressors are instrumented after testing for their endogenous/exogenous treatment. Moreover, this research adds instrumental variables other than endogenous variables in each specification to assess the validity of the instruments. Table 5.1 shows these test results that are derived from using the centers identified by the method proposed in this study and that include those instruments from the complete sets of instruments that are the most relevant and valid (the results when using the other three alternative methods or the centers of the 2010 Barcelona Metropolitan Territorial Plan are available on request).

The results of the Anderson canonical correlation (under-identification test), the Cragg-Donald F-statistic (weak-identification test), and the Shea partial R^2-statistic have shown that the instruments are relevant. The Anderson canonical correlation is statistically significant in all four specifications, meaning that it is possible to reject the null hypothesis and therefore, the instruments used are adequate to identify the equation: there is a significant relationship between the instruments (e.g., land use profile in 1956) and the endogenous variable (e.g., inverse of the distance to the nearest secondary center). The Cragg-Donald (hereafter, 'CD') F-statistic shows that the instruments used do not suffer from severe weak-identification because in all four specifications, the CD F-statistic exceeds the critical values (e.g., 10% relative bias), as provided by Stock and Yogo (2005). That means that the instruments are strong enough that they will not generate a bias of the TSLS estimator relative to the OLS estimator. These two results are reinforced by the Shea partial R^2-statistic, which shows a reasonably good value for all of the correlation coefficients, particularly with respect to the distance to the nearest secondary center. That is important because the Shea partial R^2-statistic measures the relevance of instruments by considering the intercorrelations among them when multiple endogenous regressors are used.

22 Although the data on the historical past concentration of population and human capital comes from the census provided by IDESCAT, this study elaborates the historical infrastructure developments in Catalonia based on the study of Soto and Carreras (2006-07) of the Roman roads and ING (2008) of the other historical roads and railroads. Finally, the data on historical land uses, as noted in section 5.5, are provided by AMB.

EMPLOYMENT DENSITY 2001 AND / *EMPLOYMENT DENSITY GROWTH 1991-2001*	DISTANCE TO BARCELONA (CENTRAL CITY)	DISTANCE TO THE NEAREST SECONDARY CENTER (INVERSE)	Δ DISTANCE TO THE NEAREST HIGHWAY ENTRANCE/EXIT (INFRASTRUCTURE IMPROVEMENTS)	ALL ENDOGENOUS REGRESSORS (AFTER TESTING THEIR EXOGENEITY) [TABLE 5.2/*TABLE 5.3*]
Instruments[a]	Postal roads, 1760 Population density, 1940 Land use profile, 1956[b] *Postal roads, 1760* *Population density, 1940* *Land use profile, 1956*	Postal roads, 1760 Land use profile, 1956 Non-illiterate population, 1940 *Postal roads, 1760* *Land use profile, 1956* *Non-illiterate population, 1940*	Roman roads Postal roads, 1760 Railroad network, 1935 Land use profile, 1956 *Roman roads* *Postal roads, 1760* *Railroad network, 1880* *Railroad network, 1935*	Postal roads, 1760 Land use profile, 1956 Non-illiterate population, 1940 *Roman roads* *Postal roads, 1760* *Railroad network, 1880* *Railroad network, 1935* *Population density, 1940* *Land use profile, 1956* *Non-illiterate population, 1940*
Relevance[c]				
Anderson canonical correlation	26.93** / *34.05***	53.33** / *30.77***	40.82** / *33.97***	48.30** / *46.54***
Cragg-Donald (CD) F-test	10.09 / *13.54*	24.74 / *11.93*	12.67 / *11.78*	21.15 / *11.38*
Critical value CD (10% relative bias)	9.08 / *9.08*	9.08 / *9.08*	10.27 / *10.27*	9.08 / *8.50*
Shea partial R^2				
Distance to Barcelona (central city)	0.164 / *0.208*			- / *0.269*
Distance to the nearest secondary center (inverse)		0.325 / *0.188*		0.295 / *0.440*
Δ Distance to the nearest highway entrance/exit			0.249 / *0.207*	- / *0.252*
Validity[d]				
Sargan test	4.149 / *1.263*	0.250 / *1.120*	6.290 / *3.025*	0.224 / *3.843*
Basmann test	3.997 / *1.203*	0.235 / *1.066*	6.102 / *2.894*	0.208 / *3.623*
Exogeneity[e]				
Wu-Hausman F-test	0.265 / *19.443***	*13.167** / 4.117**	0.216 / *3.765**	8.883** / *5.634***
Durbin-Wu-Hausman χ^2 test	0.280 / *18.175***	*12.841** / 4.213**	0.228 / *3.865**	8.999** / *16.410***
Observations	164 / *164*	164 / *164*	164 / *164*	164 / *164*
Regressors	8 / *7*	8 / *7*	8 / *7*	10 / *9*
Endogenous regressors	1 / *1*	1 / *1*	1 / *1*	1 / *3*
Instruments	10 / *9*	10 / *9*	11 / *10*	12 / *13*
Excluded instruments	3 / *3*	3 / *3*	4 / *4*	3 / *7*

TABLE 5.1 First stage results of two-stage least squares regressions on employment density and its growth considering the centers identified by the proposed methodology

***, * significant at 99 percent (p<0.01) and 95 percent (p<0.05), respectively.*
a. These are those combinations of instrumental variables for which relevance, validity and exogeneity perform best.
b. Land use profile is measured as the share of industrial, tertiary, and public facilities-amenities land relative to the total built-up land.
c. These tests address the underidentification and weak identification of the instruments. For example, weak identification arises when the excluded instruments are correlated with the endogenous regressors. In particular, this occurs when the Cragg-Donald (CD) F-test is below certain critical values (5%, 10%, 20% or 30%) based on bias or test size (see Stock and Yogo, 2005).
d. These statistics addresses the overidentifying restrictions. The joint null hypothesis is that the instruments are valid instruments. A rejection (p-values<0.01 or <0.05) casts doubt on the validity of the instruments.
e. The Wu-Hausman F-test and the Durbin-Wu-Hausman test assess the regressors and instruments for endogeneity. Under the null hypothesis, the specified endogenous regressors can be treated as exogenous, and thus OLS estimates are consistent.

Both the Sargan and Basmann tests indicate the acceptance of the joint null hypothesis (they are statistically insignificant) for all four specifications, and thus the instruments are valid. Finally, with regard to exogeneity tests, both the Wu-Hausman F-test and Durbin-Wu-Hausman χ^2 show that all of the endogenous variables (and their combinations) can be econometrically treated as endogenous with regard to the employment density growth models because the null hypothesis can be rejected (significant above 99% or 95% level), whereas distance to the central city and infrastructure improvements cannot be treated as endogenous when the dependent variable is the level of employment density. That means that the estimation of the employment density model using an OLS estimator and including as determinants distance to the central city (see column 2 in Table 5.1) or changes in distance to the nearest highway entrance/exit (see column 4 in Table 5.1) would not yield inconsistent results. Furthermore, these results reveal that whereas the spatial restructuring of the central city can be considered a long-term process in line with Lee and Gordon (2007), the spatial restructuring of secondary centers can be treated as a medium- or short-term process. For instance, note that this study has identified the emergence of three more centers in the Barcelona metropolitan region over a period of 10 years. In conclusion, these two tests indicate that there is evidence for an endogenous relationship not only between employment density or employment density growth and the inverse of the distance to the nearest secondary center but also between employment density growth, distance to the central city and infrastructure improvements.

Coping with spatial autocorrelation and endogeneity

However, one final estimation issue may arise from a TSLS estimation. This issue relates to spatial autocorrelation might continue to be present. In this regard, the Anselin-Kelejian test on the previous TSLS models (see the further results in Table 5.2-5.3) shows that there is spatial autocorrelation in the residuals of the estimated TSLS regressions because the null hypothesis can be rejected (it is statistically significant). To address the possible biased estimation associated with the spatial autocorrelation and the endogeneity issues arising from an OLS estimation and to obtain consistent estimates, a spatial error model can be applied using instrumental variables using General Methods of Moments (hereafter, 'GMM') techniques, following Kelejian and Prucha (1999). The main advantage of GMM techniques over simple instrumental variables techniques is that it is more efficient if heteroskedasticity (i.e., when variance of the error term conditional on response variables is not constant) is present. This tends to be the rule instead of the exception in the context of cross-sectional analysis, as in the case of this study[23]. Nevertheless, the empirical framework proposed by Kelejian and Prucha (1999) is only consistent under the assumption of the absence of heteroskedasticity. To control for heteroskedasticity, Kelejian and Prucha (2010) and Drukker et al. (2013) have proposed the incorporation of both spatial autoregressive and heteroskedastic structures for the error variance in a feasible generalized least squares procedure. The technical details of that procedure are clearly spelled out in the two studies mentioned above. In summary, the use of a Spatially Weighted Two-Stage Least Squares (hereafter, 'SWTSLS') model with a GMM estimator becomes the preferred model to empirically evaluate the polycentric model because it allows this study to control for spatial autocorrelation, recursive causality, and heteroskedasticity simultaneously. Nevertheless, to check for robustness, the results for the other models (OLS, SE and TSLS) will also be presented.

§ 5.8 Results of the evaluation of identification methods

The level of agglomeration economies and the agglomeration shadows of centers

Tables 5.2 and 5.3 present the results of applying the empirical framework to assess the polycentric model resulting from different methods by examining the determinants of employment density in 2001 (Table 5.2) and employment density growth between 1991 and 2001 (Table 5.3), respectively.

23 The econometric literature has commonly suggested the use of the Pagan-Hall test to evaluate the presence of heteroskedasticity. The results of this test obtained by considering the TSLS estimation of the employment density and employment-density growth models showed that the null hypothesis can be rejected and thus, heteroskedasticity is present. For example, the Pagan-Hall test for the job-density growth model, which considers the entropy-based centers, is 52.576 (t-value=0.00).

In these regression models, the key points of interest for evaluating the identification methods, along with the territorial model of the Barcelona Metropolitan Territorial Plan, are the following: (1) the differences in the R^2 of the model (or the adjusted or centered R^2 when appropriate given the model); and (2) the differences in the density (and the density growth) gradient associated with both the distance to the nearest secondary center and its significance level.

The differences in the R^2 value indicate how well the polycentric model for Barcelona is explained by the various identification methods. Higher R^2 values imply that the outcomes of the method fit better with the theoretical expectations of the empirical polycentric model suggested by the economics literature. The differences in the density gradient associated with the distance to the nearest secondary center reveal the level of agglomeration economies of centers (but not the central city). The higher this coefficient, the greater their distance-decay effect and thus, the more substantial the decrease of the level of agglomeration economies as distance from them increases. As explained in section 5.7, the interpretation of the estimated coefficient of the inverse of the distance to the nearest secondary center, unlike the interpretation of the coefficient of the distance to the central city, cannot be obtained directly. A more positive coefficient indicates that job density decreases with distance. The differences in the density growth gradient show the agglomeration shadows cast by these centers. The higher the density growth gradient, the greater their distance-decay effect over time, and thus the more substantial their *growth shadow effects* as one gets closer to them. However, it is not only these gradients (which represent the spatial range (geographical) of the level of agglomeration economies and agglomeration shadows of centers located beyond the central city) but also their significance level that are of importance. This phenomenon is represented by the gradients' t-values. A higher t-value of the density growth gradient, for example, means that the agglomeration shadows cast by these centers are more powerful (i.e., more statistically significant). In sum, the most accurate method will identify the set of centers with the steepest density and density growth gradients with significant t-values, and the polycentric model that they define should have the highest R^2 value.

The inclusion of the standardized coefficients of the distance to the central city and the increment of the distance to the nearest highway entrance/exit are also included to enable a comparison with the aforementioned key factor of the distance to the nearest secondary center. This comparison addresses the role played in the rise of agglomeration economies by the central city and transportation networks. For instance, if the standardized coefficient (in absolute values) of the density gradient associated with the distance to the central city is larger than the standardized coefficient of the distance to the nearest secondary center, this would mean that the distance-decay effect of the central city is greater and thus, there is a more substantial decrease in the level of agglomeration economies as one travels further from the central city. Because these (un-)standardized coefficients are semielasticities of the key factors with respect to job density or job density growth (all of the estimated models in Tables 5.2 and 5.3 are log-linear regressions), the way to interpret them is as the percentage change in a dependent variable (e.g., employment density) obtained from a 1-unit change in a key determinant (e.g., distance to the central city). Additionally, the regression models presented in Tables 5.2 and 5.3 have been estimated using the various types of models (OLS, SE, TSLS, and SWTSLS) explained in the preceding section to check for robustness and to achieve a broad conclusion about which identification method is the most accurate. To save space, the results of the control variables included in the estimation of these employment density and employment-density growth models are not presented; however, they are available upon request.

DEPENDENT VARIABLE: LN EMPLOYMENT DENSITY MAIN INDEPENDENT VARIABLES / DIAGNOSTIC TESTS METHODOLOGY FOR IDENTIFYING CENTERS / *YEAR*	DISTANCE TO BARCELONA (CENTRAL CITY)	DISTANCE TO THE NEAREST SECONDARY CENTER (INVERSE)	Δ DISTANCE TO THE NEAREST HIGHWAY ENTRANCE/ EXIT (INFRASTRUCTURE IMPROVEMENTS 1991-2001)	R-SQUARE (ADJUSTED R-SQUARE)	LM-LAG (R-LMLAG) AND LMERR (R-LMERR)[A]
OLS (ordinary least squares) models					
McDonald and Prather (1994) / *2001*					
unstandardized coefficient	-0.0418***	-0.0528	-0.0467**		
standardized coefficient	-0.3500	-0.0195	-0.1363	0.756 (0.742)	13.591*** (0.215) 21.692*** (8.316***)
t-value	-5.42	-0.43	-2.29		
García-López and Muñiz (2007, 2010) / *2001*					
unstandardized coefficient	-0.0350***	1.5920***	-0.0557***		
standardized coefficient	-0.2934	0.1837	-0.1625	0.780 (0.768)	8.158*** (0.0009) 16.158*** (8.009***)
t-value	-4.80	4.13	-2.87		
Masip and Roca (2012), following Roca et al. (2009) / *2001*					
unstandardized coefficient	-0.0461***	0.6010**	-0.0422**		
standardized coefficient	-0.3864	0.1170	-0.1231	0.766 (0.752)	17.772*** (1.291) 22.148*** (5.667**)
t-value	-6.22	2.52	-2.10		
The Barcelona Metropolitan Territorial Plan (2010 BMTP) / *2001*					
unstandardized coefficient	-0.0490***	1.5221***	-0.0602***		
standardized coefficient	-0.4111	0.1494	-0.1757	0.774 (0.761)	16.480*** (1.810) 18.686*** (4.016**)
t-value	-6.65	3.53	-3.02		
Methodology proposed in this study / *2001*					
unstandardized coefficient	-0.0366***	2.0555***	-0.0530***	0.792	
standardized coefficient	-0.3071	0.2199	-0.1545	(0.779)	8.634*** (1.111) 10.258*** (2.736*)
t-value	-5.26	5.11	-2.80		
SE (spatial error) models					
McDonald and Prather (1994) / *2001*					
unstandardized coefficient	-0.0418***	-0.1537	-0.0298		
standardized coefficient	-0.3508	-0.0568	-0.0870	0.794	
t-value	-3.84	-1.28	-1.11		
García-López and Muñiz (2007, 2010) / *2001*					
unstandardized coefficient	-0.0380***	1.3943***	-0.0429*		
standardized coefficient	-0.3186	0.1609	-0.1251	0.807	
t-value	-3.88	3.69	-1.73		
Masip and Roca (2012), following Roca et al. (2009) / *2001*					
unstandardized coefficient	-0.0474***	0.5777***	-0.0296		
standardized coefficient	-0.3970	0.1124	-0.0865	0.802	
t-value	-4.51	2.80	-1.14		
The Barcelona Metropolitan Territorial Plan (2010 BMTP) / *2001*					
unstandardized coefficient	-0.0485***	1.3771***	-0.0453*		
standardized coefficient	-0.4066	0.1352	-0.1321	0.805	
t-value	-4.80	3.35	-1.77		
Methodology proposed in this study / *2001*					
unstandardized coefficient	-0.0387***	1.6914***	-0.0424*		
standardized coefficient	-0.3246	0.1810	-0.1236	0.811	
t-value	-4.28	4.29	-1.82		

TABLE 5.2 Evaluation of the identification methods: job density pattern in 2001

**, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1), respectively.*
a. LM-LAG: Lagrange Multiplier Lag, R-LMLAG: Robust Multiplier Lag, LMERR: Lagrange Multiplier Error, and R-LMERR: Robust Lagrange Multiplier Error.
Note(s): these regression models have 164 observations and include the following control variables ($\beta_4 X_i$): distance to the nearest public-transit station (metro and train), distance to the coast, the presence of non-motorized transport, average trip distance (place of residence), concentration of best-paid occupations, and presence of urban amenities. Information (unstandardized and standardized coefficients along with t-value) about these control variables, the intercept, and the lambda parameter (e.g., for SE models) is available on request.

DEPENDENT VARIABLE: LN EMPLOYMENT DENSITY MAIN INDEPENDENT VARIABLES / DIAGNOSTIC TESTS METHODOLOGY FOR IDENTIFYING CENTERS / *YEAR*	DISTANCE TO BARCELONA (CENTRAL CITY)	DISTANCE TO THE NEAREST SECONDARY CENTER (INVERSE)	Δ DISTANCE TO THE NEAREST HIGHWAY ENTRANCE/ EXIT (INFRASTRUCTURE IMPROVEMENTS 1991-2001)	R-SQUARE (CENTERED R-SQUARE)	ANSELIN-KELEJIAN TEST (SPATIAL ERROR AUTOCORRELATION)
TSLS (two-stage least squares) models					
McDonald and Prather (1994) / *2001*					
unstandardized coefficient	-0.0410***	-0.0996	-0.0461**		
standardized coefficient	-0.3424	-0.0368	-0.1344	(0.756)	19.620***
t-value	-5.25	0.482	-2.25		
García-López and Muñiz (2007, 2010) / *2001*					
unstandardized coefficient	-0.0343***	1.7302***	-0.0564***		
standardized coefficient	-0.2878	0.1996	-0.1646	(0.770)	13.857***
t-value	-4.61	3.46	-2.89		
Masip and Roca (2012), following Roca et al. (2009) / *2001*					
unstandardized coefficient	-0.0484***	1.0061***	-0.0386*		
standardized coefficient	-0.4059	0.1958	-0.1128	(0.762)	18.696***
t-value	-6.21	2.22	-1.88		
The Barcelona Metropolitan Territorial Plan (2010 BMTP) / *2001*					
unstandardized coefficient	-0.0489***	1.4900***	-0.0600***		
standardized coefficient	-0.4099	0.1463	-0.1749	(0.774)	17.045***
t-value	-6.63	3.43	-3.01		
Methodology proposed in this study / *2001*					
unstandardized coefficient	-0.0324***	3.4990***	-0.0510**		
standardized coefficient	-0.2717	0.3744	-0.1294	(0.776)	4.642**
t-value	-4.36	4.95	-2.31		
SWTSLS (spatially weighted two-stage least squares) models					
McDonald and Prather (1994) / *2001*					
unstandardized coefficient	-0.0412***	-0.1974*	-0.0308		
standardized coefficient	-0.3572	-0.0593	-0.0894	0.752	
t-value	-3.25	-1.67	-1.41		
García-López and Muñiz (2007, 2010) / *2001*					
unstandardized coefficient	-0.0355***	1.8966***	-0.0464**		
standardized coefficient	-0.3060	0.2163	-0.1340	0.761	
t-value	-3.01	4.25	-2.23		
Masip and Roca (2012), following Roca et al. (2009) / *2001*					
unstandardized coefficient	-0.0509***	1.1061***	-0.0273		
standardized coefficient	-0.4319	0.2031	-0.0797	0.750	
t-value	-4.04	2.87	-1.11		
The Barcelona Metropolitan Territorial Plan (2010 BMTP) / *2001*					
unstandardized coefficient	-0.0488***	1.3218***	-0.0468**		
standardized coefficient	-0.4155	0.1283	-0.1350	0.764	
t-value	-3.95	5.24	-2.17		
Methodology proposed in this study / *2001*					
unstandardized coefficient	-0.0335***	3.4865***	-0.0510***		
standardized coefficient	-0.2824	0.3785	-0.1499	0.775	
t-value	-3.21	5.60	-2.73		

DEPENDENT VARIABLE: Δ LN EMPLOYMENT DENSITY MAIN INDEPENDENT VARIABLES / DIAGNOSTIC TESTS METHODOLOGY FOR IDENTIFYING CENTERS / *TIME PERIOD*	DISTANCE TO BARCELONA (CENTRAL CITY)	DISTANCE TO THE NEAREST SECONDARY CENTER (INVERSE)	Δ DISTANCE TO THE NEAREST HIGHWAY ENTRANCE/ EXIT (INFRASTRUCTURE IMPROVEMENTS 1991-2001)	R-SQUARE (ADJUSTED R-SQUARE)	LM-LAG (R-LMLAG) AND LMERR (R-LMERR)[A]
OLS (ordinary least squares) models					
McDonald and Prather (1994) / *1991-2001*					
unstandardized coefficient	-0.0153***	0.0236	-0.0304***		
standardized coefficient	-0.4506	0.0306	-0.3111	0.303 (0.267)	0.677 (3.001*) 3.102* (5.426**)
t-value	-3.92	0.42	-3.33		
García-López and Muñiz (2007, 2010) / *1991-2001*					
unstandardized coefficient	-0.0140***	0.2909	-0.0318***		
standardized coefficient	-0.4117	0.1176	-0.3248	0.311 (0.276)	0.854 (2.575*) 3.237* (4.957**)
t-value	-3.71	1.43	-3.48		
Masip and Roca (2012), following Roca et al. (2009) / *1991-2001*					
unstandardized coefficient	-0.0158***	0.1127	-0.0292***		
standardized coefficient	-0.4649	0.0768	-0.2985	0.306 (0.271)	0.705 (4.921**) 4.068** (8.284***)
t-value	-4.09	0.97	-3.19		
The Barcelona Metropolitan Territorial Plan (2010 BMTP) / *1991-2001*					
unstandardized coefficient	-0.0174***	0.4018**	-0.0339***		
standardized coefficient	-0.5110	0.1382	-0.3464	0.311 (0.279)	0.412 (3.225*) 2.706* (5.519**)
t-value	-4.51	2.26	-3.71		
Methodology proposed in this study / *1991-2001*					
unstandardized coefficient	-0.0143***	0.4377**	-0.0311***		
standardized coefficient	-0.4203	0.1641	-0.3181	0.320 (0.285)	0.756 (2.102) 2.812* (4.158**)
t-value	-3.85	2.09	-3.45		
SE (spatial error) models					
McDonald and Prather (1994) / *1991-2001*					
unstandardized coefficient	-0.0156***	0.0257	-0.0272***		
standardized coefficient	-0.4581	0.0333	-0.2786	0.326	
t-value	-3.53	0.45	-2.61		
García-López and Muñiz (2007, 2010) / *2001*					
unstandardized coefficient	-0.0142***	0.3043	-0.0287***		
standardized coefficient	-0.4169	0.1230	-0.2939	0.335	
t-value	-3.30	1.50	-2.75		
Masip and Roca (2012), following Roca et al. (2009) / *1991-2001*					
unstandardized coefficient	-0.0166***	0.1748	-0.0249**		
standardized coefficient	-0.4894	0.1192	-0.2547	0.339	
t-value	-3.67	1.62	-2.31		
The Barcelona Metropolitan Territorial Plan (2010 BMTP) / *1991-2001*					
unstandardized coefficient	-0.0175***	0.3992**	-0.0308***		
standardized coefficient	-0.5155	0.1373	-0.3150	0.332	
t-value	-4.06	2.09	-2.99		
Methodology proposed in this study / *1991-2001*					
unstandardized coefficient	-0.0144***	0.4246**	-0.0281***		
standardized coefficient	-0.4240	0.1592	-0.2871	0.340	
t-value	-3.43	1.97	-2.74		

TABLE 5.3 Evaluation of the identification methods: job-density growth pattern 1991-2001

****, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1), respectively.*
a. LM-LAG: Lagrange Multiplier Lag, R-LMLAG: Robust Multiplier Lag, LMERR: Lagrange Multiplier Error, and R-LMERR: Robust Lagrange Multiplier Error.
Note(s): these regression models have 164 observations and include the following control variables ($\beta_4 X_4$): distance to the nearest public-transit station (metro and train), distance to the coast, average trip distance (place of residence), concentration of best-paid occupations, and employment density (initial year: 1991). Information (unstandardized and standardized coefficients, along with t-value) about these control variables, the intercept, and the lambda parameter (e.g., for SE models) is available on request.

DEPENDENT VARIABLE: Δ LN EMPLOYMENT DENSITY MAIN INDEPENDENT VARIABLES / DIAGNOSTIC TESTS METHODOLOGY FOR IDENTIFYING CENTERS / *TIME PERIOD*	DISTANCE TO BARCELONA (CENTRAL CITY)	DISTANCE TO THE NEAREST SECONDARY CENTER (INVERSE)	Δ DISTANCE TO THE NEAREST HIGHWAY ENTRANCE/ EXIT (INFRASTRUCTURE IMPROVEMENTS 1991-2001)	R-SQUARE (CENTERED R-SQUARE)	ANSELIN-KELEJIAN TEST (SPATIAL ERROR AUTOCORRELATION)
TSLS (two-stage least squares) models					
McDonald and Prather (1994) / *1991-2001*					
unstandardized coefficient	-0.0239***	0.0408	-0.0649***		
standardized coefficient	-0.7034	0.0529	-0.6633	(0.238)	2.794*
t-value	-4.57	0.61	-3.80		
García-López and Muñiz (2007, 2010) / *1991-2001*					
unstandardized coefficient	-0.0239***	0.3059	-0.0733***		
standardized coefficient	-0.7013	0.1237	-0.7496	(0.218)	3.203*
t-value	-4.75	1.20	-4.34		
Masip and Roca (2012), following Roca et al. (2009) / *1991-2001*					
unstandardized coefficient	-0.0212***	0.0575	-0.0530***		
standardized coefficient	-0.6233	0.0392	-0.5415	(0.276)	2.761*
t-value	-4.23	0.33	-3.43		
The Barcelona Metropolitan Territorial Plan (2010 BMTP) / *1991-2001*					
unstandardized coefficient	-0.0265***	0.6426***	-0.0699***		
standardized coefficient	-0.7788	0.2211	-0.7146	(0.256)	2.563*
t-value	-4.98	2.71	-4.04		
Methodology proposed in this study / *1991-2001*					
unstandardized coefficient	-0.0212***	0.7659***	-0.0615***		
standardized coefficient	-0.6243	0.2872	-0.6290	(0.292)	2.567*
t-value	-4.45	2.50	-3.87		
SWTSLS (spatially weighted two-stage least squares) models					
McDonald and Prather (1994) / *1991-2001*					
unstandardized coefficient	-0.0227***	0.0513	-0.0488***		
standardized coefficient	-0.6713	0.0738	-0.4794	0.268	
t-value	-4.16	0.82	-3.29		
García-López and Muñiz (2007, 2010) / *1991-2001*					
unstandardized coefficient	-0.0217***	0.2665	-0.0532***		
standardized coefficient	-0.6413	0.0977	-0.5232	0.262	
t-value	-4.08	1.10	-3.61		
Masip and Roca (2012), following Roca et al. (2009) / *1991-2001*					
unstandardized coefficient	-0.0229***	0.1742	-0.0450***		
standardized coefficient	-0.6774	0.1159	-0.4430	0.287	
t-value	-4.08	1.14	-3.08		
The Barcelona Metropolitan Territorial Plan (2010 BMTP) / *1991-2001*					
unstandardized coefficient	-0.0246***	0.5565**	-0.0541***		
standardized coefficient	-0.7194	0.1893	-0.5260	0.289	
t-value	-4.56	2.54	-3.69		
Methodology proposed in this study / *1991-2001*					
unstandardized coefficient	-0.0212***	0.5927**	-0.0516***		
standardized coefficient	-0.6137	0.2186	-0.4932	0.290	
t-value	-4.08	2.25	-3.61		

The OLS regressions in Table 5.2 highlight that the identification method that best explains the polycentric model in the Barcelona metropolitan region is the method proposed in this study. This is consistent across all of the other model specifications (SE, TSLS, and SWTSLS) considered. For instance, the R^2 value of the SWTSLS regressions is 0.776 when the set of entropy-based centers is considered, whereas it decreases to 0.752 and 0.760 when centers identified by different density-based methods are employed and 0.750 and 0.764 when the flow-based centers and the centers of the 2010 Barcelona Metropolitan Territorial Plan are taken into account. Furthermore, the level of agglomeration economies in this set of centers is the highest because these entropy-based centers have the steepest distance-decay effect, and this effect is strongly statistically significant. Again, this finding remains largely similar across the various model specifications presented in Table 5.2. The steeper distance-decay effect of the entropy-based centers also indicates that the difference between their level of agglomeration economies and the level of agglomeration economies of the surrounding areas is comparatively larger. This means that the areas surrounding those entropy-based centers benefit more from their proximity to these centers because they can access a higher level of agglomeration economies. For example, if the standardized coefficient associated with the distance to the nearest secondary center is analyzed across all model specifications (OLS, SE, TSLS, and SWTSLS), for each 1 kilometer from the nearest secondary center, the degree of employment density decreases at least by 18.10% when entropy-based centers are identified. By contrast, that degree is reduced to a minimum of 11.24% when centers are detected using the other methods (density-based and flow-based) or a minimum of 13.52% when the centers of the Barcelona Metropolitan Territorial Plan are considered.

Table 5.3 presents a dynamic perspective to evaluate the polycentric model by examining the trends in employment density between 1991 and 2001. The identification method that best explains the development of agglomeration economies over the Barcelona metropolitan region is the method proposed in this chapter because R^2 values of the polycentric models estimated by considering entropy-based centers are the highest across all model specifications. It was previously argued that agglomeration shadows are particularly likely to manifest themselves in growth differences between centers and their surrounding areas. If the agglomeration shadows cast by different sets of centers are considered, the results obtained for all types of the regression models indicate that entropy-based centers exert the most severe *growth shadow effects* over their surroundings because they experience the most substantial distance-decay effect over time. This phenomenon indicates that the development of agglomeration economies in the areas surrounding these entropy-based centers is more limited because they exert a stronger competition effect over their neighboring areas. For instance, if the standardized coefficient associated with the distance to the nearest secondary center is examined across all model specifications, for each 1 kilometer increase from the nearest secondary center, the level of employment density growth in the areas within that radius has decreased at least by 15.92% since 1991, when entropy-based centers are taken into account. In contrast, this level is reduced to a minimum of 13.73% when the centers of the Barcelona Metropolitan Territorial Plan are considered. It is important to note that the agglomeration shadows of the centers identified using the density-based and the flow-based methods are nonexistent because their distance-decay effects are not statistically significant. This means that the set of potential centers identified by these empirical identification methods does not completely fit this study's new theory-informed conceptualization of what a center is. Centers are not only places with the highest level of agglomeration economies in a metropolitan area but also places that cast the most wide-ranging (spatially) and powerful agglomeration shadows over their surroundings.

These findings for the regression models of employment density and employment density growth lead to the conclusion that the entropy-based method of identifying centers proposed in this study is the most accurate to define the polycentric model in Barcelona. This is because the agglomeration shadows of the centers identified by the entropy-based method are the most severe and because that method identifies those centers with the highest level of agglomeration economies.

Testing the equality between coefficients

However, whereas the previous regression models (Tables 5.2-5.3) were primarily focused on comparing whether the density gradient or the density growth gradient associated with a set of centers identified by one method were (statistically) significantly larger than the gradients associated with a set of centers detected by another method on the basis of the null hypothesis, no attention has been paid to the question of whether these differences are (statistically) significantly different (e.g., δ_2[entropy-based method] - δ_2[flow-based method] = 0). Testing the significance of the difference among density gradients across methods could more comprehensively confirm the previous conclusion (entropy-based method being more accurate) because it will show if the highest level of agglomeration and the most severe agglomeration shadows of the entropy-based centers also significantly differ from the level of agglomeration economies of other sets of centers and their agglomeration shadows. This analysis, which is denoted as the test of equality between coefficients, is reported in Table 5.4.

COEFFICIENT TESTED: Distance to the nearest secondary center (inverse) in models that include centers identified by the method proposed in this study compared to models that include centers detected by using existing identification methods:	MCDONALD AND PRATHER (1994)	GARCÍA-LÓPEZ AND MUÑIZ (2007, 2010)	MASIP AND ROCA (2012), FOLLOWING ROCA ET AL. (2009)	THE BARCELONA METROPOLITAN TERRITORIAL PLAN (2010 BMTP)
	DENSITY-BASED METHOD	DENSITY-BASED METHOD	FLOW-BASED METHOD	(NON-EMPIRICAL METHOD)
Employment density models				
OLS (ordinary least squares)				
Chi-square statistic	38.44***	6.02**	16.48***	4.22**
Probability>chi-square	0.0000	0.0249	0.0000	0.0465
TSLS (two-stage least squares)				
Chi-square statistic	34.45***	9.24***	11.96***	8.75***
Probability>chi-square	0.0000	0.0024	0.0005	0.0031
Employment density growth models				
OLS (ordinary least squares)				
Chi-square statistic	7.23***	3.37*	5.92**	0.31
Probability>chi-square	0.0072	0.0564	0.0150	0.5763
TSLS (two-stage least squares)				
Chi-square statistic	5.08**	3.21*	5.36**	0.19
Probability>chi-square	0.0242	0.0774	0.0206	0.6632

TABLE 5.4 Testing the difference between coefficients of the distance to the nearest secondary center in the estimated employment density and employment density growth models

****, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1), respectively.*
Note(s): test of equality examines whether the difference between two coefficients is statistically significant. In that regard, Table 5.4 tests whether the coefficient of the distance to the nearest secondary center when centers are identified by the method proposed in this study significantly differs from the coefficient of the distance to the nearest secondary center when other identification methods are used.

The results of the test of equality between coefficients reveal that the difference between the density gradient associated with the entropy-based centers, the density gradient related to the centers identified by using alternative methods and the centers of the 2010 Barcelona Metropolitan Territorial Plan is statistically significant above 95% (see the value of the chi-square statistic and its significance level). That means, for example, that the level of agglomeration economies of the centers identified through the entropy-based method is comparatively more substantial than the level of the centers proposed by the Barcelona Metropolitan Territorial Plan, and this difference (e.g., δ_2[2.0555***] - δ_2[1.5221***] = 0) is significant for better explaining the polycentric model in Barcelona because the test of equality presents a significant chi-square statistic of 4.22**. However, the test of equality between coefficients has also shown that although the difference between the density growth gradient associated with the entropy-based centers and the density growth gradient related to centers detected by using other methods is statistically significant, the test of equality between coefficients is not significant when the gradient associated with the entropy-based centers is compared to the gradient related to the centers of the Barcelona Metropolitan Territorial Plan. In a sense, this may indicate that there would have been a slight difference between the method proposed in this study and the territorial model of the aforementioned spatial plan in identifying the centers that most accurately define the polycentric model in Barcelona if the unique viewpoint of analysis had been the study of the centers' agglomeration shadows.

The role played by infrastructure improvements

The results of Tables 5.2 and 5.3 have also revealed the role played by infrastructure improvements in the rise of agglomeration economies. The interpretation of the coefficient of the changes in 1991-2001 distance to the nearest highest highway entrance/exit can be obtained as follows. A more negative (lower) coefficient indicates that the level of job density or employment density growth experiences more of an increase near infrastructure improvements because a higher reduction in the distance of municipalities to the highway system entails greater infrastructure improvements. In general, the effects of proximity to highway improvements between 1991 and 2001 are statistically significant for the degree of employment density and its subsequent growth over time. The municipalities with the most improved accessibility to the transportation infrastructure had greater employment concentration in 2001 and have increased that concentration over time. In addition, when re-estimating the previous models (results not reported) by using the distance to the nearest highway in 1991 instead of infrastructure improvements (1991-2001), it was found that the municipalities that were to the highway networks in 1991 had a higher level of employment density in 2001 and have experienced positive growth in employment density since 1991. These observations seem to indicate that transportation infrastructures and their improvements generate agglomeration economies that lead to the spatial concentration of firms (e.g., proxied by employment density) spread out along the current infrastructure network and new highways.

Comparing the standardized β coefficients shows that the effect of infrastructure improvements (decreasing distance to the nearest highway entrance/exit over time) appears even stronger than the distance-decay effect of the nearest center (but not the central city) in the area of employment density growth (Table 5.3). However, that effect is less important with respect to explaining current levels of employment concentration (Table 5.2). In other words, for the concentration of employment, firms' mutual interest in locating close-by to enjoy cost advantages remains more important than their motivation to increase accessibility. This finding is consistent with the findings of other studies mentioned in section 5.2. However, with respect to growth in firm concentration, as proxied by employment density growth, increased accessibility becomes more important. This substantiates section 5.5's observation that since 1991, infrastructure improvements have facilitated the appearance of centers such as Sant Cugat del Vallès (-2.88 km) and Rubí (-2.02 km) along the B-30 infrastructure corridor and El Prat de Llobregat (-2.43 km) and Cornellà de Llobregat (-0.63 km) along the radial roads from the central city of Barcelona.

Nature of the agglomeration economies of the entropy-based centers

Table 5.5 presents the estimation of the polycentric model by distinguishing the nature of the agglomeration economies of the entropy-based centers at two time points and in two categories: 'large' centers and 'emerging' centers. As stated in section 5.4 (and in chapter 2, section 2.3), it can be expected that the different origin of centers (decentralization or incorporation-fusion) is significant to their level of agglomeration economies as well their agglomeration shadows. Table 5.5's comprehensive empirical analysis adds valuable insights into this expectation. More specifically, it was argued that centers arising out of incorporation-fusion (i.e., 'large' or 'high-order' centers) have a higher level of agglomeration economies and cast more spatially wide-ranging and powerful agglomeration shadows than centers arising out of decentralization (i.e., 'emerging' or 'low-order' centers) because the former can organize greater urbanization (advantages) economies because of their larger city size and more diversified economic structure.

MAIN INDEPENDENT VARIABLES / DIAGNOSTIC TESTS	DISTANCE TO BARCELONA (CENTRAL CITY)	DISTANCE TO THE NEAREST LARGE CENTER (INVERSE)	DISTANCE TO THE NEAREST EMERGING CENTER (INVERSE)	R-SQUARE (ADJUSTED R-SQUARE)
Dependent variable: Ln Employment density / *year*				
OLS (ordinary least squares) models				
1991 unstandardized coefficient	-0.040***	2.666***		
standardized coefficient	-0.3436	0.2706		0.592 (0.574)
t-value	-4.60	4.94		
2001 unstandardized coefficient	-0.036***	2.266***		
standardized coefficient	-0.3083	0.2461		0.733 (0.721)
t-value	-4.72	5.25		
1991 unstandardized coefficient	-0.050***		2.386***	
standardized coefficient	-0.4259		0.2410	0.580 (0.5613)
t-value	-5.50		4.37	
2001 unstandardized coefficient	-0.037***		2.194***	
standardized coefficient	-0.3144		0.2414	0.732 (0.721)
t-value	-4.82		5.24	
Dependent variable: Δ Ln Employment density / *time period*				
SWTSLS (spatially weighted two-stage least squares) models				
1991-2001 unstandardized coefficient	-0.021***	0.562**		
standardized coefficient	-0.6220	0.2030		0.292
t-value	-4.14	2.39		
1991-2001 unstandardized coefficient	-0.021***		0.516**	
standardized coefficient	-0.6199		0.1875	0.285
t-value	4.07		2.03	

TABLE 5.5 Nature of the agglomeration economies of different centers as identified by the entropy-based method

****, **, * variables significant at 99 percent ($p<0.01$), 95 percent ($p<0.05$) and 90 percent ($p<0.1$), respectively.*
Note(s): these regression models have 164 observations and include the following control variables ($\boldsymbol{\beta}_4\boldsymbol{X}_i$): Δ distance to the nearest highway entrance/exit (infrastructure improvements 1991-2001), distance to the nearest public-transit station (metro and train), distance to the coast, average trip distance (place of residence), concentration of best-paid occupations, and employment density (initial year: 1991). Information (unstandardized and standardized coefficients, along with t-value) about these control variables, the intercept, and the lambda parameter (for SWTSLS models) is available on request.

The results show that 'large' centers have a higher level of agglomeration economies and cast more severe agglomeration shadows than do 'emerging' centers (as becomes obvious from the higher value of their density gradients and the higher t-values associated with these gradients). This finding is consistent with the centers' characterization in section 5.4, which predicted that 'large' centers' agglomeration economies are more attenuated than 'emerging' centers' agglomeration economies by distance. However, the results have also revealed that the density gradient of the 'emerging' centers has decreased, indicating that these centers have not developed more powerful agglomeration economies since 1991. This does not match the a priori expectation (see section 5.4). There could be two reasons for this unexpected finding. First, the development of stronger agglomeration economies might be hampered by their tendency to be located near the central city, which has a spatial influence that has persisted over time. Examples of the central city's persistent influence include not only that its agglomeration economies are higher-level than those of secondary centers but also that it casts a more severe agglomeration shadow (see the higher values of the central city's density gradients set forth in Tables 5.2-5.5). Second, the post-1991 increase in centers' spatial integration could also have implied that the 'emerging' centers did not develop more powerful agglomeration economies because they have been affected by the *growth shadow* of other centers (excluding the central city).

§ 5.9 Conclusion

To explore the link between polycentricity and performance, it is necessary to identify a sound method of identifying centers in metropolitan areas. From my perspective, current methods do not provide a satisfying approach. This chapter first aimed to develop an alternative method of identifying centers in metropolitan areas using the Barcelona metropolitan region as a case study. The outcomes of this new identification method have been compared not only with the centers identified using other well-known methods in the literature but also with the centers identified in the 2010 Barcelona Metropolitan Territorial Plan. The outcomes of all of the different methods were benchmarked not only against their fit with the theoretical and empirical (polycentric) models suggested by the economics literature but also against the question of where actual development has taken place. These two analyses have enabled this study to fulfill its second aim, which was to determine which method of identifying centers is the best for a subsequent examination of the alleged economic, social, and environmental dis(advantages)of polycentricity and how they can inform planning.

The novel identification method proposed in this study, which uses employment entropy measures, has several important benefits. First, this method considers the distinct origins of center formation (i.e., decentralization and incorporation-fusion), which have a significant relationship to the nature of agglomeration economies, according to the New Urban Economics and New Economic Geography frameworks. Thus, the polycentric model's advantages could be dependent on those origins. Second, this method considers both the spread of employment as a proxy for the spatial concentration of agglomeration economies over the metropolitan area and flows between places as a proxy for their capacity to play a central role in the surrounding territory. This consideration allows the method proposed in this study to bridge the gap between the US- and Europe-based literatures on the identification of centers because it incorporates each distinct pathway to polycentricity into a single identification method. Third, this method addresses many of the main modeling drawbacks that affect the methods in the literature that are used to identify centers. More specifically, the entropy-based method has three main advantages over the identification methods explained in section 5.3. First, unlike the threshold-based and hybrid approaches, the entropy-based method does not require a degree of local knowledge to identify centers and thus, this method could facilitate cross-country or even cross-metropolitan area research. Second, the 'small' center problem does not affect the entropy-based method to the same extent that it affects the econometric-based methods (e.g., a parametric function or spatial econometric techniques), which too easily identify centers at the peripheries of metropolitan areas when those centers actually play only a minor role in terms of employment. This phenomenon is attributable to the fact that entropy measures quantify the spatial concentration of employment in each spatial unit relative to the entire geographical (metropolitan) system, not the near surroundings only (see section 5.4). Third, unlike the other methods, the entropy-based method considers the attenuation with distance of the agglomeration economies of the central city to identify centers and thus, it more closely follows the theories of the New Urban Economics and the New Economic Geography. However, a potential disadvantage is that required flow data on geographically detailed scales is not always available. This drawback may imply that the choice of the unit of analysis is often dependent on the spatial level at which mobility data are available. Consequently, the identification of centers has been performed on a municipal scale, not on any smaller scales.

The empirical framework built in this chapter to evaluate the polycentric model advanced by the economics literature was novel not only because it considered the *growth shadow effects* of centers and the role played by infrastructure improvements but also because it controlled for bias resulting from both recursive causality and spatial autocorrelation. According to this theory-informed framework, the entropy-based method developed in this study performs better than the other identification methods, and the centers identified using this method are more accurate than the centers identified in the 2010 Barcelona Metropolitan Territorial Plan. This is because these centers' agglomeration shadows are the most severe and these centers' level of agglomeration economies is the highest.

This evaluation of the polycentric model highlights two other important findings. First, the origin of centers has an impact on the attenuation with distance of their agglomeration economies. More specifically, centers arising out of incorporation-fusion tend to be characterized by a higher level of agglomeration economies and cast a more spatially wide-ranging, more powerful agglomeration shadow than do those centers originating from decentralization. This confirms the expectation that urbanization economies dominate over localization economies in centers arising out of incorporation-fusion because of their (in general) larger city size and more diversified economic structure. Second, infrastructure improvements significantly foster the development of agglomeration economies (proxied by the growth of employment density) that follow the infrastructure transportation networks. The development of agglomeration economies due to an increase of accessibility has contributed to the rise of new centers along the B-30 infrastructure corridor (such as Sant Cugat del Vallès and Rubí) and along the radial roads from Barcelona (such as El Prat de Llobregat and Cornellà de Llobregat).

These exact centers were identified when using the novel entropy-based method, but generally were not identified when using the other methods. Those centers are justified because they are the sites of major new urban development projects, and they have experienced a substantial transformation in land use over the course of time in accordance with their origin (incorporation-fusion and decentralization). That notwithstanding, these centers were not identified in the 2010 Barcelona Metropolitan Territorial Plan.

In conclusion, the entropy-based method proposed by this chapter is a better approach to identifying centers and (subsequently) the polycentric territorial model of a metropolitan area than existing methods; in addition, it is more accurate than the (non-empirical) process that led to identifying the centers in the 2010 Barcelona Metropolitan Territorial Plan. This conclusion has two main implications. First, integrating the distinct literatures on the formation of centers improves the identification of centers, which is important for defining polycentric development strategies for metropolitan areas. Second, the centers identified by the novel method in this chapter should provide the starting point for performing additional research steps in this dissertation. Chapter 6 advances the question of how polycentricity has been identified and measured in research and how this identification and measurement of polycentricity can inform the understanding of polycentric development in planning. More specifically, chapter 6 quantifies Barcelona's metropolitan spatial structure and discusses how that structure can inform spatial plans.

6 Quantifying the metropolitan spatial structure of Barcelona

§ 6.1 Introduction

In recent decades, there has been growing interest in polycentricity as a planning vision in which polycentricity is read as a normative objective to enhance the performance of metropolitan areas. Notably, the planning literature (e.g., Davoudi, 2003; Schmitt, 2013) and spatial plans—see, e.g., the 2010 Barcelona Metropolitan Territorial Plan—have argued that polycentric development policies prompt not only a more balanced spatial distribution of population, economic activities, and urban functions but also higher levels of functional integration and complementarity among centers across a metropolitan area. That said, little is known about metropolitan areas' internal spatial organization and their development over time. Spatial planning, as shown in the introduction to this thesis, has advanced purely theoretical ideas of the polycentricity concept, thereby overlooking how well the attempt to implement polycentric development fits into the reality of contemporary metropolitan areas. In addition, some empirical studies have questioned the extent to which a metropolitan structure evolves into a polycentric form (Burger et al., 2011), or whether major cities in a polycentric urban region are truly both functionally integrated (Hanssens al., 2014) and complementary (Meijers, 2005, 2007b). This problem could be partially attributed to the lack of conceptual clarity with respect to the concept of polycentricity, which can mean different things at distinct geographical scales and hence, it is unsurprising that there is a lack of consensus about how to measure the spatial organization of metropolitan agglomerations (see section 2.2 in chapter 2). Therefore, it can be argued that it would be desirable to renew the measurement of metropolitan areas' internal urban structures and discuss how those structures inform spatial plans. Because a polycentric configuration cannot exist without a minimum spatial balance in the distribution of urban attributes, a minimum level of spatial integration, and complementarity among the centers of the metropolitan area, a lack of empirical evidence of polycentricity may create doubt about the wisdom of supporting the polycentric development that has been initiated by many spatial plans in Europe and the United States (see Table 1.1 in the introduction to this thesis).

The aim of this chapter is not only to quantify Barcelona's internal metropolitan structure and development since 1991 but also to discuss that structure in relation to polycentric development policies. Building upon a conceptual model to guide the direction of the research (Figure 6.1), this study answers the specific research question (see section 2.5 in chapter 2) of the extent to which the metropolitan structure of Barcelona can be considered polycentric from a morphological and functional perspective and how that structure can inform planning practice. Answering this specific research question could provide useful evidence-informed knowledge of the current level of polycentricity, which can not only support the definition of effective and feasible polycentric development strategies but also enable monitoring of their implementation (see Figure 1.3 in the introduction to this thesis). To adequately address this question, it is necessary to formulate three subquestions to guide our exploration of the metropolitan spatial structure. Each of those subquestions represents a distinct, but overlooked aspect of the inter-urban polycentricity literature (see Figure 6.1) that must be considered to improve the measurement of polycentricity on the intra-urban scale. First, to what extent are centers' urban attributes and functional linkages becoming more evenly distributed across the metropolitan area? Second, to what extent is the existence of multiple centers in close proximity accompanied by strong functional linkages among them? Indirectly, the question becomes whether the metropolitan area operates as a functionally integrated entity. Third, to what extent are relationships among centers complementary instead of competitive? This last question addresses the division of labor among the centers of the Barcelona metropolitan region (as defined in chapter 5).

The discussion of these questions is embedded (see Figure 6.1), as suggested by previous research (Burger et al., 2014b, 2014c), in the exploration of multiplexity (the spatial organization of different types of urban networks not being identical) and individual-level heterogeneity (variety in spatial interaction patterns that can be attributed to differences among people or firms). The manner in which these two refinements are translated into this research is by considering a variety of flows of people, who are differentiated by their motivation to travel (e.g., for work, leisure, and social visits) and their attributes (e.g., gender, age and educational level) when measuring polycentricity. In addition, this study considers the occupational and the industrial (sectoral) structure of the regional economy (see Barbour and Markusen, 2007) in the measurement of morphological and functional polycentricity (see Figure 6.1). One reason to explore the geography of occupations (particularly those involving skilled labor) is that as economic development of regions seems to have become strongly dependent on the mix of occupations instead of the mix of industrial labor because of the growing appreciation for human capital (Markusen 2004; Markusen and Schrock, 2006), the study of the geography of occupations can deliver key insights into the ongoing transformation of the urban structure in contemporary metropolitan areas (Duranton and Puga, 2002, 2005). Additionally, including this third refinement as a way to measure the degree of polycentricity enables this research to renew the intra-urban polycentricity literature. For instance, no studies of complementarities among centers have adopted a sectoral- and occupational-based perspective.

The remainder of the chapter is organized as follows. Section 6.2 reviews the approaches of the inter-urban polycentricity literature to measure polycentricity following the conceptual model presented in Figure 6.1. Section 6.3 explains the lack of clarity in polycentricity measurement and defines the main challenges for measuring polycentricity. Section 6.4 presents the data and methods used in this study. Section 6.5 presents the findings from the analysis of morphological and functional polycentricity. Finally, section 6.5 sets out the main conclusions and discusses how polycentricity measurement can inform planning practice.

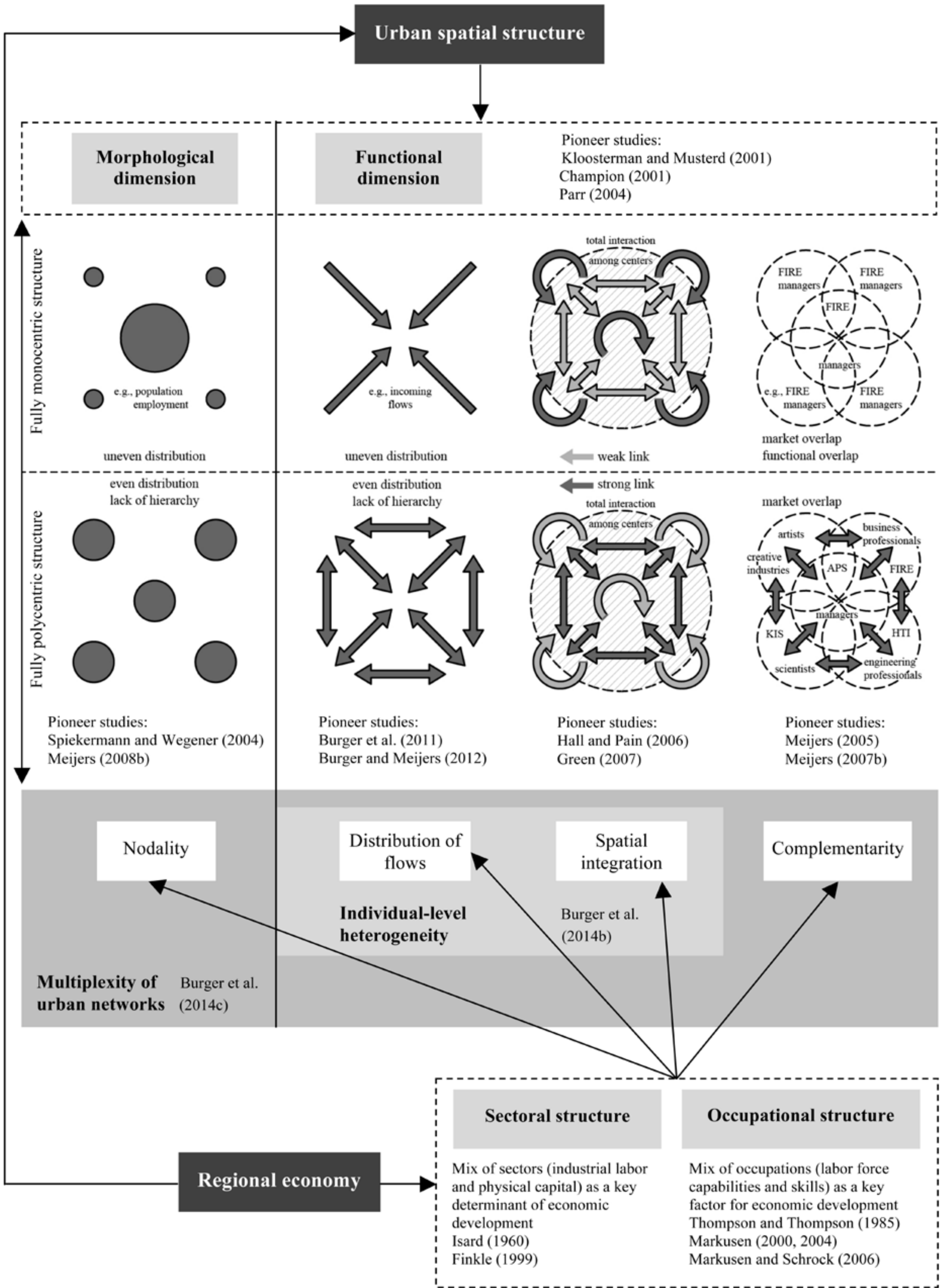


FIGURE 6.1 Conceptual model for quantifying the spatial organization of urban systems

Own elaboration based on the contributions of Meijers (2005, 2007b), Burger et al. (2011), Burger and Meijers (2012), and Burger et al. (2014c).

§ 6.2 Approaches to measuring polycentricity

The origins of the current debate in the literature about how to measure polycentricity might be rooted in three pioneering contributions that have provided a detailed definition of a polycentric urban system. First, Kloosterman and Musterd (2001) have defined a polycentric system as follows: (1) a collection of historically distinct cities; (2) located in more-or-less close proximity to each other, leading to important functional relationships among them; (3) where there is a lack of clear hierarchy in political, economic, cultural, and other aspects. Second, Champion (2001) has remarked that polycentric systems are defined by three cumulative characteristics: (1) they are a collection of settlements; (2) there is functional interaction among them; and (3) each center has a specialist function within the system. Third, Parr (2004) has extended the previous two definitions by highlighting seven specific conditions. A polycentric system is (1) a set of centers that are physically separated because of the existence of, (2) an upper and (3) a lower limit on such separation, where there is (4) a lack of dominance in the centers' size distribution, (5) a correlation between the size and spacing of centers, (6) a certain amount of spatial integration attributable to economic interactions among centers, and (7) important complementarities attributable to the centers' specialized profiles.

As can be observed, these three definitions have all underlined the absolute or relatively equal importance of certain cities in terms of their urban attributes and relationships to determine what a polycentric system is. In this regard, scholars who have attempted to quantify the degree of polycentricity of urban systems have disentangled two clear, distinct dimensions (see Figure 6.1). The first dimension, morphological polycentricity, tends to be associated with a balanced distribution with respect to the absolute importance (nodality) of the centers in terms of their urban attributes (e.g., population). The second dimension, functional polycentricity, focuses on various aspects of the interactions among centers in relation to their relative importance. These two dimensions of polycentricity are addressed in detail below.

Morphological polycentricity

Because morphological polycentricity is associated with a balanced distribution with respect to the absolute importance of centers, the pioneer studies of Spiekermann and Wegener (2004) and NORDREGIO (2005) have used the rank-size distribution of population and GDP, along with accessibility, the primacy rate of population and GDP, and the Gini coefficient of service areas and accessibility to measure the degree of polycentricity using functional urban areas as spatial units. The idea coined by these studies was that the flatter the slope of the rank-size distributions or the lower the primacy rate, the more polycentric the urban system as the distribution of cities becomes increasingly uniform.

This empirical approach led to the creation of two main groups to quantify the degree of morphological polycentricity. The first group uses the rank-size distribution among centers based on population (Burger et al., 2014a; Hall and Pain, 2006; Meijers, 2008b; Meijers and Burger, 2010; Vasanen, 2013; Veneri and Burgalassi, 2012), jobs (Burger and Meijers, 2012; Melo et al., 2012), or shoppers (Burger and Meijers, 2012). However, the application of the rank-size distribution in the manner proposed by the ESPON 1.1.1 Project (NORDREGIO, 2005), which is based on using the number of functional urban areas as the sample, could lead to the potential problem that some urban systems appear to be more polycentric than they really are because of the inclusion of a larger number of smaller functional urban areas. For this reason Meijers (2008b) proposes the use of a fixed number of centers in the sample (e.g., the largest 2, 10, or 20) instead of the total number of geographic units. This approach was well received among scholars: later studies have followed Meijers's approximation. Examples include

Burger et al. (2014a), who have considered the largest 2, 3 and 4 centers as a sample to quantify the degree of polycentricity, and Veneri and Burgalassi (2012), who have used the largest center together with cities whose populations are higher than the median population in the urban system.

The second group examines the lack of hierarchy by using a set of indicators that measures the main center's degree of dominance (e.g., a country's main functional urban area) relative to the entire urban system under analysis (e.g., the country). In these terms, the relative concentration of population (Veneri and Burgalassi, 2011) or employment (Burger et al., 2011), a cardinal ranking based on five distinct indicators (IGEAT, 2007), and a score index of population (Vandermotten et al., 2008) have been used to quantify morphological polycentricity. Perhaps the fact that this second approach has overlooked the extent to which the other major cities have contributed to a less hierarchical urban system could explain why this approach has received less attention in the literature.

Functional polycentricity

Measuring functional polycentricity is perhaps more complex than quantifying the degree of morphological polycentricity, although there are similarities in that both approaches focus on measuring the importance of centers. Approaches to measuring functional polycentricity focus on three distinct dimensions: the distribution of flows, the extent of spatial integration, and the level of complementarity (see Figure 6.1).

Functional polycentricity: the distribution of flows

For the first dimension of functional polycentricity, which focuses on the distribution of flows, the direction of linkages among centers is the key focal point of analysis. An equal balance in the distribution of flows among centers means that the functional relationships are directed at multiple centers and consequently, two-way flows among centers exist. Whether an urban structure can be considered polycentric depends on the extent to which such multi-directional flows appear.

Several approaches have been developed to study this aspect of polycentricity. First, some scholars have used a set of indicators to define centers' degree of centrality as a proxy for the direction of flows. For example, Van der Laan (1998) and Van Nuffel and Saey (2005) have defined distinct polycentric commuting patterns (decentralized, exchange, and cross-commuting) across daily urban systems in the Netherlands and city-regions in Flanders, respectively, using indicators based on commuting such as outward and inward openness, which measure the centrality of centers within a urban system. Similarly, other studies have used alternative indicators such as dominance measures (Burger et al., 2011; Hall and Pain, 2006; IGEAT, 2007; NORDREGIO, 2005), or node-and-link symmetry (balance between in- and out-flows) indexes (Limtanakool et al., 2007, 2009) to determine the degree of centrality and thus, the extent to which functional linkages are bidirectional. For instance, Burger et al. (2011) have proposed a functional indicator called the 'primacy functional index', which measures the ratio between in-flows that a center receives from other centers relative to the total in-flows of the urban system. Another good example is the research conducted by Van Nuffel et al. (2010) and Hanssens et al. (2014), who have developed a set of indicators to assess functional polycentricity following Limtanakool et al. (2007, 2009), but controlling for the sensitivity issue related to the number of spatial units by using standard deviations and rank-size distribution indexes, thus representing improved accuracy when metropolitan areas containing many spatial units are studied. Whereas the first study proposes a non-directional dominance index to assess air passenger flows in Europe, the second defines a relative centrality index based on using advanced producer service transaction links data to examine functional polycentricity in the mega-city region of Central Belgium.

Second, another approach measures the extent to which interactions among centers are bidirectional and evenly spatially distributed across the urban system. This value has been empirically tested in two distinct ways. On the one hand, a body of literature has used entropy measures, which relate the centrality of a geographic unit to the distribution of flows within a system, to quantify the degree of polycentricity related to business, holiday, and leisure flows in France and Germany (Limtanakool et al., 2007), travel-to-work and leisure flows in the Netherlands (Limtanakool et al., 2009), and work flows in Italy (Veneri and Burgalassi, 2012). On the other hand, another body of literature has originated the idea of combining one functional indicator that captures the direction of flows (e.g., primacy functional index) with the use of rank-size distributions to test the uniformity of its spatial distribution (Burger and Meijers, 2012; Burger et al., 2014c).

A third approach has propounded the idea of the connectivity field (Vasanen, 2012). The connectivity field determines how intensively a center is functionally connected to the rest of the urban system by examining its in-flows. This third approach yields a main peculiarity compared to the other two approaches. It considers the distribution of flows that comprise all of the in-flows' origins, not merely the total number of in-flows that a center receives. Therefore, this approach may capture the directions of the in-flows more precisely. To assess the balance of the distribution of centers across the urban system, Vasanen (2012) has regressed the connectivity value of each center on the distance to the central city. The flatter the slope of this regression, the greater the degree of functional balance and thus, the more polycentric the urban system.

Functional polycentricity: spatial integration

The second dimension of functional polycentricity is spatial integration. This perspective on polycentricity not only is based on the strength of the functional linkages among centers but also reflects the extent to which the centers are interdependent within a urban system. In this regard, in a hypothetical polycentric system that is fully spatially integrated, the actual flows among the centers do not differ significantly from the total potential flows. In addition to the first attempt by the ESPON 1.1.1 project (NORDREGIO, 2005) to quantify spatial integration by identifying potential polycentric integration across Europe, four main approaches can be distinguished.

The first approach uses the indicator of network density proposed by Green (2007) to determine the extent to which various parts of an urban system are functionally interdependent. In this manner, Burger et al. (2011) have defined the potential connection between all of the different spatial units in the city-regions of England and Wales by considering their total number of employees. Burger and Meijers (2012) have applied the network density indicator to 42 functionally coherent regions in the Netherlands, and Burger et al. (2014c) have used network density at the overall and subregional internal network levels by considering three different networks (daily activities, intra- and inter-firm) in the Randstad. Second, another approach illustrates the degree of spatial integration by estimating a gravity model (Champion and Coombes, 2014; De Goei et al., 2010; Hanssens et al., 2014; Van Oort et al., 2010) in which the key conditions that must be tested to corroborate the existence of spatial integration, as noted by Van Oort et al. (2010:735-736), are the following: (1) intra-urban linkages should not be stronger than interdependencies between cities, (2) interdependencies within one subregion should not be more prominent than the linkages across all subregions, and (3) an observable strong hierarchy could not be present. Third, other studies (Limtanakool et al., 2007, 2009; Van Nuffel et al., 2010) have evaluated spatial integration by defining a relative strength index that estimates the flow proportion of a single link between two centers relative to the total interaction. Finally, Vasanen (2013) has proposed that spatial integration could also be quantified by using the concept of the connectivity field (Vasanen, 2012). The argument is that the connectivity field also captures the degree of the intensity with which workers living in a particular location commute to a center relative to the distribution of all origin locations in the urban system.

At this stage, it is important to make a spatial integration-related distinction that has been noted by some scholars (Burger and Meijers, 2012; Burger et al., 2011, 2014c). They remark that a spatially integrated system may have a highly unbalanced and one-way orientation of flows leading to a highly functional, integrated monocentric system, whereas a highly functionally balanced flow system may be weakly spatially integrated. Indeed, this argument is supported by the findings of those studies that have examined spatial integration using gravity models. Whereas some studies have highlighted that there is no evidence of spatial integration (Hanssens et al., 2014; Van Oort et al., 2010), other research (De Goei et al., 2010) has found some evidence of polycentric development attributable to the increment of the strength of the interdependencies in suburban areas. In a sense, the literature has concluded that whereas some spatial integration can be a prerequisite for understanding an urban system as polycentric, the two-way orientation and a balanced distribution of flows are fundamental criteria for distinguishing between polycentric and monocentric structures. Following this line of reasoning, the use of hybrid methodologies proposed by some scholars to simultaneously test both of the mentioned aspects of functional polycentricity could be less appropriate given the extent to which the fundamental criteria for defining a functional polycentric system (balanced distribution of flows) may not be accomplished. This is the case with studies that have simultaneously tested the even distribution of functional linkages among centers and their strength using indicators built from network density, for example, using the general functional polycentricity index (Green, 2007; Hall and Pain, 2006; Maturana and Arenas, 2012; Veneri and Burgalassi, 2011, 2012) because the urban system under analysis can present a high degree of functional polycentricity that is attributable to the fact that such a system is highly spatially integrated.

Functional polycentricity: complementarity

The third dimension of functional polycentricity is complementarity. Although this dimension has been relatively less studied in the literature, it is not less relevant than other dimensions. As Champion (2001) and Parr (2004) have stated, polycentric structures imply that centers have some minimal degree of complementarity that is reflected in distinct economic profiles, which in turn may lead to an overlapping of their market areas, resulting in functional integration. However, regional economists have stated, from a different viewpoint, that complementarity can also be perceived as a particular division of labor. The point is that some type of spatial division of labor occurs through the shape of specialization processes and the spatial concentration of industries (e.g., Marshall, 1920). Both meanings are joined in the studies of Meijers (2005, 2007b), which have defined complementarity as the division of labor among cities that is derived from supply and demand: "*two cities are complementary when one specializes in, for instance, financial services and the other in transport and logistical services, each also providing these services to business or citizens located in the other city*" (Meijers, 2005:770). Additionally, as Burger et al. (2013) have argued, substitutive or competitive relationships arise when centers fulfill the same role and function and thus, there is a certain level of sectoral and organizational overlap among them.

Meijers (2005, 2007b) has explored the level of complementarity in the Randstad polycentric urban region by applying correspondence techniques, an approach that was followed in studies of complementarity in the San Francisco Bay Area, Randstad and Emilia-Romagna (Cowell, 2010) and the 'Saxony Triangle' (Franz and Hornych, 2010). Other scholars have developed methods that do not involve applying correspondence techniques to study this third dimension of functional polycentricity. Whereas Van Oort et al. (2010) have proposed a complementarity index based on considering the specialization and interaction among centers by measuring their concentration of jobs and firms, Burger et al. (2013) have developed a competition indicator by considering inter-firm relations. However, the extent to which a polycentric urban system has a complementary structure has not been empirically substantiated in the literature. Whereas some studies have found decreasing sectoral complementarities (specialization) in the polycentric urban regions analyzed (e.g., Cowell, 2010; Meijers, 2005, 2007b), other research has revealed an increasing sectoral differentiation among the major cities within a polycentric urban region (Franz and Hornych, 2010).

§ 6.3 The measurement of polycentricity: a lack of clarity

The preceding review of the literature on how to measure the degree of polycentricity within urban systems has illustrated that the complexity surrounding the concept of polycentricity has led to a wide variety of approaches and interpretations, resulting in a lack of consensus about how to measure polycentricity. Part of the complexity or *lack of clarity* related to the measurement of polycentricity can be attributed to the scale-dependent interpretation of the concept of polycentricity. Moreover, it can be argued that two refinements need to be incorporated into the measurement of polycentricity. First, it is important to pay attention to multiplexity and individual-level heterogeneity that influences the pattern of flows when studying polycentricity. Second, when studying morphological and functional polycentricity, there is a need to consider both of the conceptions of the regional economy suggested by the existing literature on regional economic development: i.e., the industrial structure and the occupational structure of regions.

Scale-dependent interpretation of polycentricity

The main issue that hampers the measurement of the degree of polycentricity is related to the fact that polycentricity refers to different concepts when it is measured on distinct spatial scales (Davoudi, 2003). For instance, polycentricity can be applied on the intra-urban scale (see chapter 2), where it traditionally has referred to the appearance and identification of centers in metropolitan areas that once were monocentric but have evolved to become more polycentric. This acceptance of polycentricity, which can be framed within the theoretical frameworks of the New Urban Economics and New Economic Geography models as explained in chapter 5, has primarily led to quantification of the urban spatial structure by measuring the decentralization-concentration patterns of employment, as noted by Anas et al. (1998). Two main morphological approaches to quantifying polycentricity have arisen in this context. The first approach analyzes how the density gradients associated with centers have changed over time (see the literature review in chapter 5: e.g., McMillen and Lester, 2003). The flatter the slope of the density gradient related to the distance to the central city, the greater the decentralization and thus, the greater the spread of employment across the metropolitan area, which in turn may form several centers. The second approach considers how employment concentration has evolved in metropolitan areas over time. These concentrations have been frequently examined, for example, by analyzing the absolute and relative job growth in centers compared to the rest of the metropolitan area or by using spatial concentration indicators such as location quotients and Gini coefficients. Both approaches have defined a particular body of literature that aimed to examine whether job decentralization, particularly with respect to high-order and knowledge-based sectors, is occurring and if so, what spatial form it has taken: dispersed, polycentric, or both (see, e.g., Coffey and Shearmur 2002; Halbert, 2004; Pfister et al., 2000; Shearmur and Coffey, 2002; Shearmur et al., 2007).

That said, polycentricity can also be understood on an inter-urban scale as a collection of large, distinct but close-by historical cities with no clear hierarchy (thus defining what the literature has called a polycentric urban region) and in which the centers' morphological and functional characteristics are the key point of analysis (e.g., Hall and Pain, 2006; Kloosterman and Musterd, 2001; Meijers, 2005, 2007b; Parr, 2004). Additionally, polycentricity can refer to the functional interaction among global city-regions (e.g., Taylor et al., 2008; Van Nuffel et al., 2010) where because of the global scale involved, physical proximity among centers—and thus, the morphological dimension of polycentricity—becomes less relevant.

This scale-dependent interpretation of polycentricity may lead one to perceive an urban system as polycentric on one scale and monocentric on another (Hall and Pain, 2006) because the trajectories of urban systems toward polycentric spatial configurations occurring on distinct territorial scales simultaneously (Burger et al., 2014c; Champion and Coombes, 2014; De Goei et al., 2010; Taylor et al., 2008; Van Oort et al., 2010; Vasanen, 2013). For example, De Goei et al. (2010) have found that polycentric development is occurring on an intra-urban, not an inter-urban scale, whereas Burger et al. (2014c) have revealed that the Randstad is polycentric on an inter-urban scale but quite monocentric on an intra-urban scale.

It seems therefore that an adequate approach to measuring polycentricity may build upon a joint approach to quantifying polycentricity on both the intra- and inter-urban scales. From the perspective of this study, the measurement of the degree of polycentricity should take stock of the existing advantages of the current literature on both scales. In this regard, an analysis of the urban structure that follows the narrow approach of the intra-urban scale's studies only quantifies the morphological dimension because it does not address the functional dimension of the spatial organization that is characteristic of polycentricity studies on the inter-urban scale. In contrast, the inter-urban literature pays less attention to identifying the centers that define the spatial organization of an urban system, which in turn has a substantial impact on the measured degree of polycentricity. An urban system may appear to have a lower degree of polycentricity (e.g., a very uneven distribution of flows) than it actually has because certain spatial units (e.g., municipalities) that are centers and therefore should have been included in the measurement of polycentricity have not been considered because they are not identified as centers. In summary, there seems to be a great deal of improvement in measuring polycentricity when both approaches are united in a single framework.

Multiplexity of urban networks and individual-level heterogeneity

Recent contributions by Burger et al. (2014b, 2014c) put us on the track of an important refinement in measuring polycentricity and spatial structure in general. When considering the functional dimension of the urban structure, one must consider the issues of both 'multiplexity' and 'individual-level heterogeneity'. In other words, different types of functional linkages (or flows) among centers do not necessarily follow the same spatial logic (multiplexity), and even when considering one type of flow, individual characteristics (of persons, firms) are also very significant to the appearance of flows (individual-level heterogeneity). Indeed, Burger et al. (2014c) have found that shopping, social visits, business travel and buyer-supplier relationships among centers are organized in a polycentric manner in the Randstad polycentric urban region, whereas subsidiary-headquarters links are clearly monocentric. Burger et al. (2014b), in turn, have revealed the importance of distinguishing subgroups (e.g., of people and firms) to accurately analyze various patterns of linkages. For instance, highly educated people are more prepared to travel on a higher spatial scale, and thus they reinforce the degree of functional polycentricity on the inter-urban scale. In contrast, less well-educated people are more likely to travel within their own urban regions, which may suggest a more monocentric pattern on the intra-urban scale.

Consequently, it seems that evaluating an urban structure by only examining one type of functional linkage such as travel-to-work flows (Vasanen, 2012, 2013) and (advanced producer services) transaction links (Hanssens et al., 2014)—or even two (Limtanakool et al., 2007) such linkages—and only considering general patterns of such flows may be insufficient to obtain broad conclusions about the extent to which an urban system is polycentric.

Regional occupational and industrial structure

Another refinement in the measuring of polycentricity arises out of scholars' lack of interest in using the occupational conception of the regional economy to quantify the degree of polycentricity. Regional economists generally pay a great deal of attention to the types of industrial labor (and their mix) that may increase regions' competitiveness and economic development when developing strategies to replace declining industries (Finkle, 1999; Isard, 1960). Economic development planners have often employed the industrial depictions made by regional economists to target key industries for local economic development, which involves policies aimed at attracting firms and countering firms' out-migration in the desired sectors (Markusen, 2004). This conception of the regional economy may explain intra-urban polycentricity studies' increasing interest in exploring intra-metropolitan location patterns of employment in relation to knowledge-based sectors such as advanced producer services, financial insurance and real estate to examine whether they have decentralized in a polycentric form (see, e.g., Coffey and Shearmur, 2002; Hoyler et al., 2008; Muñiz and García-López, 2010; Shearmur and Alvergne, 2002, 2003; Shearmur and Motte, 2009). These studies have argued that the evolution of the spatial pattern of knowledge-based sectors into a more polycentric pattern (higher concentration in several centers) indicates that centers' agglomeration benefits (e.g., greater opportunities for firms to establish face-to-face contact) play a major role in their spatial distribution over the metropolitan area. Additionally, knowledge-based sectors' trend toward polycentricity may indicate a greater economic competiveness for these polycentric regions because of businesses' increased presence in distinct centers and their intense connection to the global-based economy (see, e.g., Castells, 1989; Pain and Hall, 2008).

That notwithstanding, the regional economy's industrial (sectoral) structure has not been the only approach that regional economists have suggested using to foster regional economic development. The pioneer research of Thompson and Thompson (1985) pays a great deal of attention to the types of work available in the local economy, thus suggesting that labor force capabilities and skills are a more important determinant of economic development than the mix of industrial labor and physical capital. More recently, the literature has focused on 'what people do' (occupations) instead of 'where people work' (sectors). One body of literature has argued that regional economic development has become increasingly dependent on local knowledge bases and human capital and because occupations can capture their contributions more directly, an occupational-based approach to regional economic development is better than an industrial-based one (e.g., Feser, 2003; Markusen, 2004). Markusen (2004:255) has argued, for example, not only that skilled labor can be studied as members of an occupation but also that key occupations (e.g., performing artists) increase the productivity and performance of a range of firms and industries, both indirectly and via their role in creating, attracting, and retaining firms and thus, jobs. Additionally, she has argued that by identifying and targeting occupations that appear to (1) be highly skilled, (2) show growth potential, (3) cluster spatially, (4) cross-fertilize with other sectors, (5) encourage entrepreneurship, and (6) match the potential of the area workforce, planning practitioners could elaborate policies that facilitate economic competitiveness and social equity goals.

Another body of literature—this one more closely related to urban economics—has also highlighted the increasing importance of the occupational structure to understand the ongoing transformation of the urban structure in contemporary metropolitan areas (e.g., Bade et al., 2004; Barbour and Markusen, 2007; Duranton and Puga, 2002, 2005; Markusen and Schrock, 2006). Essentially, these studies argue that because of the transformation in the internal organization of firms, which implies an increased separation between management and production functions, a new division of labor and specialization trends across the metropolitan space has emerged. For example, Duranton and Puga (2002, 2005) have argued that US cities are increasingly distinguished by functional (occupational)—not sectoral—specialization, and although high-order firm functions such as headquarters remain located in the central cities, other functions such as advanced manufacturing activities have been clustered in second-ranked cities. This finding was later corroborated by Bade et al. (2004) and Barbour and Markusen (2007), who found an important functional division of labor developing in German cities and in California based on an increasing presence of 'white-collar' functions (managerial and professional) in central locations and a strong presence of 'blue-collar' functions (manufacturing) in peripheral locations.

Notwithstanding this growing interest in the occupational conception of the regional economy, studies on the link between occupational geography in metropolitan areas and polycentricity remain scarce. In practice, one can expect the development of a polycentric spatial configuration to be significant to the location pattern of occupations, especially high-order occupations (knowledge workers) because such occupations may prefer to be spatially clustered in centers to benefit from agglomeration advantages. In a sense, it can also be argued that when the measurement of morphological and functional polycentricity considers the spatial distribution of occupations across a metropolitan area, a better understanding of how people locate by occupation (e.g., where people with high-tech occupations have chosen to live and work) is facilitated, which in turn helps planners craft an occupational targeting strategy. For example, exploring occupational-based complementarities among centers not only shows the level of specialization of centers in certain highly skilled occupations (and therefore those occupations' level of spatial clustering) but also could identify key inter-occupational relations among occupations that are relatively more concentrated in a particular center.

The challenges of measuring polycentricity

The challenges of quantifying metropolitan spatial structures, particularly polycentricity, follow quite naturally from the three issues discussed above. There is scope for innovation that unites the intra- and inter-urban approaches to measuring polycentricity in a single framework, considering not only the multiplexity of urban networks and individual-level heterogeneity but also the regional occupational and industrial (sectoral) structure when examining morphological and functional polycentricity. The three sub-research questions addressed in the remainder of this chapter reflect these three issues:

1. To what extent are centers' urban attributes and functional linkages becoming more evenly distributed across the metropolitan area?
2. To what extent is the existence of multiple centers in close proximity accompanied by strong functional linkages among them?
3. To what extent are relationships among centers complementary instead of competitive?

Section 6.4 details the data and methods used to answer these questions.

§ 6.4 Research approach: data and methods

Data

To address the research questions set forth above, this chapter draws on two data sources. The use of these sources enables this study to explore the degree of morphological and functional polycentricity by considering the two refinements suggested in section 6.3. Whereas the use of population and mobility data derived from the census enables this research to measure morphological and functional polycentricity (i.e., distribution of flows, spatial integration, and complementarities) by also considering the regional occupational and sectoral structure, the use of mobility data from the Daily Mobility Survey (*Enquesta de Mobilitat Quotidiana* (hereafter, 'EMQ')) enables this study to account for multiplexity and individual-level heterogeneity when measuring polycentricity.

The population census data are obtained from the *Institut d'Estadística de Catalunya* (hereafter, 'IDESCAT') and provide the number of inhabitants for each municipality in the Barcelona metropolitan region for 1991, 1996, 2001, and 2011. The mobility data obtained by the census provide exhaustive information about the adult (over 16 years of age) population's travel-to-work trips between all of the municipalities in the Barcelona metropolitan region. From this data, the number of jobs and in-commuting flows is easily derived. IDESCAT also provides a dataset for 1991, 1996 and 2001 that considers both the total bulk of flows and the disaggregate flow with regard to sectors and occupations at the 1-, 2-, and 3-digit levels. The sectoral classification is the CCAE-93 Rev.1 and consists of 17 sectors at the 1-digit level, 62 sectors at the 2-digit level, and 224 sectors at the 3-digit level. The occupational classification is denoted CCO-94 and is based on 9 occupations at the 1-digit level, 66 occupations at the 2-digit level, and 207 occupations at the 3-digit level. From a combination of these sectoral and occupational classifications at the 2- and 3-digit levels, the knowledge-based sectors and knowledge workers have been defined as follows.

The classification of the knowledge-based sectors consists of 28 individual sectors grouped into 5 main groups (see Appendix 6.1): high-technology industries; finance, insurance and real estate; knowledge-intensive services; advanced producer services; and creative industries. To define each group's sectors, this research follows the finance, insurance and real estate and the advanced producer services classifications proposed by Coffey and Shearmur (2002), the high-technology industries and knowledge-intensive services classifications suggested by the OECD (2003), and the creative industries classifications defined by Méndez et al. (2012). The classification of knowledge workers groups 22 occupations into 8 main categories (see Appendix 6.2): management, business professionals, science and engineering professionals, science-technical occupations, health professionals, other health-technical occupations, education, law and social science-related professionals, and arts and culture professionals. To define each category's occupations, this chapter uses the occupational classifications suggested by Beckstead and Vinodrai (2003), Markusen (2004), and Barbour and Markusen (2007).

Recently, 2011 census data were made available by IDESCAT and the *Instituto Nacional de Estadística* (hereafter, 'INE'). The word 'census' conceals the fact that only a sample of the population was questioned[24], meaning that the data on commuting are less exhaustive than before. Still, the 2011

24 These limitations are related to the fact that the 2011 census does not provide a complete count of the population and instead is elaborated by a survey sample. More specifically, 199,480 surveys (representing 2.5% of Catalonia's total population) include information about trip origins and destinations. This sample is only available for municipalities with more than 80,000 inhabitants. However, IDESCAT has published a table that contains the number of jobs, resident workers, the resident employed population, incoming flows, and outgoing flows for all Catalonia's municipalities with more than 2,000 inhabitants. In addition, this second sample is available not only for the total bulk of flows but also at the disaggregate level for economic sectors and occupations at the

census can be used. The centers identified in chapter 5 all exceed the threshold of 2,000 inhabitants, the minimum size for which data were made available. Additionally, 2011 census data classified by sectors and occupations at 1-digit level allow a comparison with past census editions by aggregating the 17 sectors and 9 occupations of the 2001, 1996 and 1991 census data into the 10 sectors (CCAE-2009 classification) and 9 occupations (CCO-2011 classification) defined by the 2011 census. Unfortunately, the 2011 census data do not provide information about sectors and occupations in more detail, limiting my ability to conduct a more detailed study of the knowledge-based sectors and occupations.

The EMQ elaborated by the Metropolitan Transportation Authority (*Autoritat del Transport Metropolità* (hereafter, 'ATM')) of Barcelona was designed to collect comprehensive information for the attributes of all trips (e.g., purpose, transportation mode) made by an individual during a single week (7 consecutive days). Additionally, EMQ data contain information about a variety of individual-specific characteristics (e.g., gender, age, and educational level). Since 1996, ATM has performed EMQs every 5 years. This research selected the EMQs for 1996, 2001, and 2006. Unfortunately, the 2011 edition remained unavailable at the time of writing. Although the 2006 edition provides a less intense examination of the Barcelona metropolitan region[25], this fact does not prevent an accurate evaluation of Barcelona's internal metropolitan structure given that the centers identified in chapter 5 also exceed the threshold of 50,000 inhabitants, for which the 2006 EMQ provides significant statistical information. To address multiplexity of urban networks when measuring polycentricity, this study considers the various trip purposes mentioned in the EMQ data. Given the 12, 14 and 23 distinct trip purposes in the 1996, 2001, 2006 EMQ, respectively, some trips were aggregated to allow for a longitudinal analysis of different types of flows. The following seven trip purposes are included: work, business, education, leisure, shopping, social-visit, and health travel. Purposes that were not related to work or business were grouped in a 'non-work-related travel' category. To address individual-level heterogeneity, the available data allows the consideration of various individuals' characteristics relative to each trip purpose. This task has been performed by using the individual-specific characteristics of trip-makers provided by the 1996, 2001, and 2006 EMQs, thus enabling this investigation to perform a comparative analysis over time. Those characteristics are as follows: gender (male, female), age cohorts (<16, 16-45 years, 45-65 years, >65) and educational level (less-well-educated, medium-educated and highly educated).

Methods

Morphological and functional (distribution of flows) polycentricity

The degree of morphological polycentricity and functional polycentricity is determined following the approach of Burger and Meijers (2012) and Burger et al. (2014c). Therefore, this study focuses on the balance in centers' importance in terms of their nodality and centrality in the metropolitan area. According to this study's analysis, nodality scores, which proxy for the degree of morphological polycentricity, are based on the total number of inhabitants, total employment (also considering knowledge-based sectors and knowledge workers), and the total number of people who engage in some type of activity (defined by the seven trip purposes, thereby taking stock of multiplexity). This

1-digit level. Whereas the sectoral classification is named CCAE-2009 and consists of 10 sectors, the occupational classification is named CCO-2011 and is based on 9 occupations.

25 Unlike previous editions, the 2006 EMQ is extended to the entire Catalan territory and is not exclusively focused on the Barcelona metropolitan region. However, this caused the 2006 EMQ to provide only information about travel on trips generated in municipalities within the Barcelona metropolitan region that have more than 50,000 inhabitants.

last category then sums the incoming flows to a center and flows that both originate at and stay in the same center. The centrality scores proxy the degree of functional polycentricity and are based on the number of incoming flows that a center receives for travel-to-work trips (the bulk of flows disaggregated by sectors and occupations) and for each type of trip purpose (multiplexity), which is subsequently subdivided according to individual characteristics (e.g., gender, etc.).

A metropolitan area is consider to be more polycentric when its centers are more equal in terms of importance, thus implying less hierarchy. As Burger and Meijers (2012) and Burger et al. (2014c) state, the rank-size distribution is a proper indicator to assess the importance of centers because it measures the degree of hierarchy among centers. This research adheres to that view and thus, it employs rank-size distributions of the nodality and centrality scores by using the log-log form with Ordinary Least Squares (hereafter, 'OLS') techniques and by estimating the parameter values of the rank-size regressions, following the approach of Gabaix and Ibragimov (2011), which addresses the potential bias of small samples. The remaining question is how many centers are needed to determine this hierarchy. Meijers (2008b) argues that a fixed number is best, and this study defines two sample sizes based on using a fixed number of the centers identified in chapter 5. These two analyses enable this research to check for robustness. Whereas the first sample includes the 10 largest (or most central when functional polycentricity is measured) centers (N=10) in line with Burger et al. (2014c), the second sample uses distinct numbers of the largest or most central centers (N=2, 3, 4), following Meijers and Burger (2010).

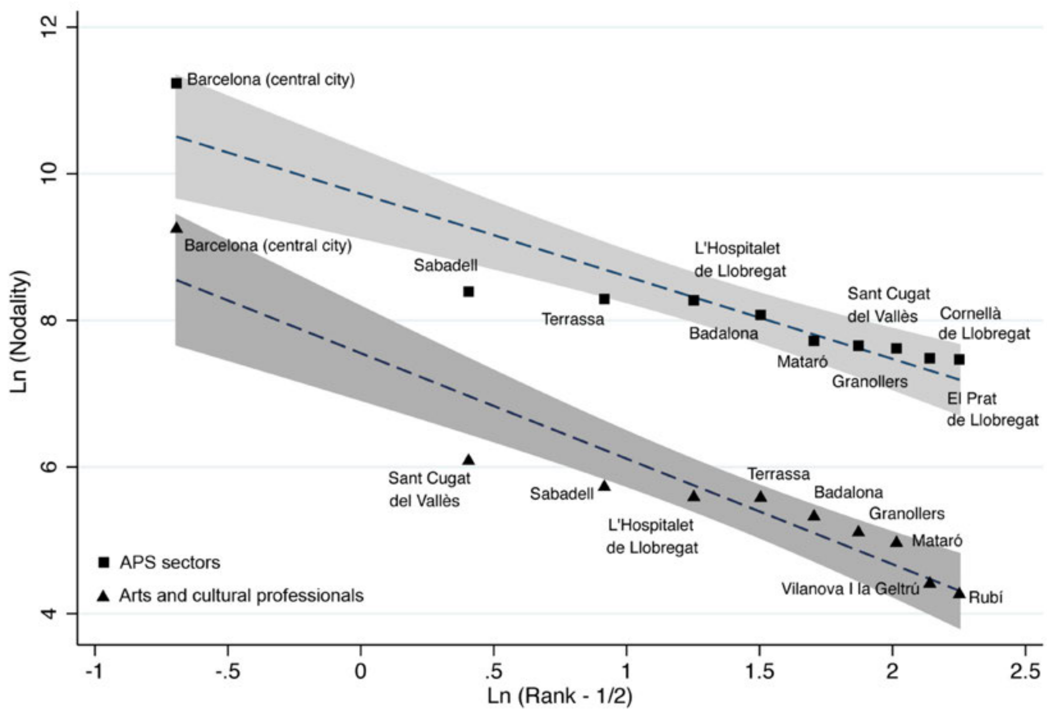


FIGURE 6.2 Rank-size distributions measuring morphological polycentricity

Note(s): APS represents jobs in advanced producer services. Employment data come from the 2001 residence-to-work travel dataset provided by IDESCAT (Institut d'Estadística de Catalunya).

Therefore, the morphological (or functional) polycentricity indicator is the slope of the regression line that best fits the rank-size distribution of centers. This slope is represented by the estimated β coefficient of the rank size regression. For example, Figure 6.2 shows how a rank-size distribution is interpreted to measure polycentricity. It depicts two rank-size distributions, one of which considers the 10 largest centers in terms of advanced producer services jobs and the other of which considers jobs occupied by arts and cultural professionals. Additionally, these rank-size distributions show the regression line (slope) and its 95% confidence interval. The interpretation is as follows. The higher (less negative and closer to 0) the (β) coefficient (see rank-size distribution in terms of jobs in advanced producer services), the flatter the slope of the rank-size regression and thus, the more polycentric the metropolitan area because there is a lesser degree of hierarchy. In contrast, the steeper the slope of the rank-size regression (see the rank-size distribution of arts and cultural professionals), the more monocentric the metropolitan area. It is important to mention that the (β) coefficients (slopes of the rank-size regressions) take values that range from 0 (perfectly polycentric) to -∞ where a value of -1 suggests some degree of monocentricity, as noted by Burger et al. (2014c).

Functional polycentricity: spatial integration

With respect to the spatial-integration dimension of functional polycentricity, this study follows previous research (Burger and Meijers, 2012; Burger et al., 2011, 2014c) that suggests the use of the network density indicator proposed by Green (2007) to measure the extent to which centers are functionally linked. The network density indicator is calculated as the proportion of the number of actual flows among centers to the number of potential flows among them. Determining this number of potential flows, however, is not straightforward, and Green's (2007) proposal to relate it to centers' resident populations (i.e., the sum of the entire resident population in centers minus the lowest value of the resident population among these centers) is unsatisfying because it does not consider the observed pattern of flows among centers. To address that issue, this research adopts the empirical modification of the network density introduced by Maturana and Arenas (2012), who have proposed a more robust network density computation that results in a potential flow measure that is a maximum value calculated in relation to the actual observed pattern of flows among centers. More specifically, this refinement of the network density is based on maximizing the result obtained from (1) multiplying the maximum value of the normalized flows for each of the centers with the sum of the total flows in each center and then (2) subtracting the minimum number of normalized flows in terms of those people who travel from the value obtained in the multiplication performed in the first step (see Maturana and Arenas, 2012:45 for more technical details). Additionally, it is noteworthy that this study does not combine the network density scores with another indicator of the balanced distribution of flows (e.g., the general functional polycentricity index of Green, 2007); this is to avoid biased results on the degree of functional polycentricity, as explained in section 6.2.

Therefore, the functional polycentricity indicator for measuring the degree of spatial integration will be the network density proposed by Maturana and Arenas (2012), and it will be applied to the different types of trips between the centers identified in chapter 5, thus accounting for the regional sectoral and occupational structure, the multiplexity of urban networks, and individual-level heterogeneity. The interpretation of the network density indicator is as follows. Its value ranges from 0 to 1 and the higher the value, the greater the extent to which centers are intensely functionally interconnected and therefore, the greater the metropolitan area's propensity to operate as a functional integrated entity for this type of flow. A value of 0.5 or above indicates strong connectivity among centers because previous research has noted that a value of network density between 0.05 and 0.25 indicates that centers are functionally linked (see Burger et al., 2014c; Green, 2007; Hall and Pain, 2006).

Functional polycentricity: complementarity

The method employed to examine the third dimension of functional polycentricity—complementarities among centers—is correspondence analysis, which is a technique to analyze the association between distinct complex information organized into rows and columns in a matrix denoted as a contingency table. This technique enables the representation of the information on the contingency table in a low-dimensional Euclidean space. In that Euclidean space, categories with a similar distribution will be represented as points that are near in space, and categories with a very distinct distribution will be displayed far from each other. For a detailed explanation of the correspondence analysis technique, see Greenacre (1993) and Clausen (1998).

The use of this method in the social sciences is not new and it has long been applied to explanatory data analysis (e.g., Benzecri, 1992) and the measurement of complementarity in polycentric urban regions (Cowell, 2010; Franz and Hornych, 2010; Meijers, 2005, 2007b). Although often used as a tool to enable the graphic interpretation of complex data, correspondence analysis provides a simple statistical measure that defines the extent of differentiation in the profiles of a group of geographic units; thus, it is particularly well suited to study complementarity among centers in a metropolitan area. This statistic is called total inertia, which is a measure of the extent to which the profile points of a category (e.g., center) are spread around a centroid, which in turn represents the average profile. The larger the distance from the category points to the centroid, the higher the inertia and the more distinct the distribution. Inertia's highest possible value is equal to the dimensionality of the problem (in this research, the number of centers – 1). This maximum would be achieved if all the centers have a completely different profile (e.g., in terms of sectors or occupations), whereas zero inertia is attained when all the centers have the same profile.

The centers that this study uses to examine (complementary or competitive) relationships are those identified in chapter 5. These centers' profiles are represented by their sectoral and occupational profile, and various levels of detail are used (1 digit in general, and 2-3 digits when considering knowledge-based sectors and occupations). In addition, a profile of the centers' urban functions is made based on the purpose of people's daily activities in a center. To enable a comparison of the inertia among the various centers of the Barcelona metropolitan region since 1991, this research uses the complementarity ratio proposed by Meijers (2005), except for an empirical modification of the calculation of the inertia statistic to achieve a more robust analysis. At first glance, this complementarity ratio normalizes the total inertia by dividing it by the maximum total inertia and multiplying the result by 100, resulting in a score of between 0 and 100. However, this indicator cannot control for general tendencies and shifts in employment in the economy. It could be that the same activities continue to take place in a city but become less labor-intensive (for instance, in industry). To address that issue, this study proposes the use of the total inertia that results from controlling for the active margins of the contingency table by giving equal weight to each column (e.g., sector, occupations, or daily activities). This empirical modification must be considered an improvement upon the aforementioned studies of complementarity within polycentric urban regions.

§ 6.5 Morphological and functional polycentricity in Barcelona: results

Morphological polycentricity

The results of the morphological polycentricity measurement, which considers the multiplexity of urban networks and the regional occupational and sectoral structures, are shown in Table 6.1 (columns 1 and 2). These results are based on the first sample size (N=10) considered in this study to estimate rank-size regressions, whereas the results from the second sample size (N=2, 3, 4) are available on request because they lead to similar findings. As a benchmark, the slopes of the rank-size regression in terms of population (-0.92) and employment (-0.97) in 2011 show that morphologically, Barcelona is only a slightly polycentric metropolitan region compared to other urban systems in Europe, such as the Randstad polycentric urban region, which has a more even distribution of population (-0.31) and employment (-0.42) (numbers taken from Burger et al., 2014c). The percentages in the second column indicate the trend in the level of polycentricity since the initial year (which varies between 1991 and 1996). Here, a negative number means that the distribution over the centers became more polycentric, whereas a positive percentage indicates a more monocentric distribution. For instance, although the spatial distributions of population (-6.65%) and jobs (-12.18%) became more even since 1991 (perhaps because of the emergence of new centers and the development of a polycentric structure, see chapter 5), the central city of Barcelona continues to play a prominent role in the Barcelona metropolitan region. In this regard, the low coefficients (far from zero) for the rank-size regressions of the knowledge-based sectors and occupations in 2001 (the most recent year in this case) reveal an even stronger nodality (absolute importance) for the central city of Barcelona. In particular, the slope of the rank-size regression for arts and cultural professionals in 2001 (-1.44) indicates that their distribution is actually quite monocentric, being strongly concentrated in Barcelona. The knowledge-based occupations that are comparatively more spread out are found in the scientific-technical domains.

With regard to the differences from other types of flows, especially related to shopping, work and social visits, the distribution seems to be more even than the general spread of population and jobs, and the relatively high (closer to zero) rank-size coefficients suggest a more morphologically polycentric structure. In contrast, business, education, leisure, and health travel flows are relatively more unevenly distributed, indicating a greater concentration of these urban functions in the central city of Barcelona.

DIMENSION OF THE URBAN SPATIAL STRUCTURE TIME PERIOD UNDER ANALYSIS (1991-2011[1], 1991-2001[2], 1996-2006[3])	MORPHOLOGICAL POLYCENTRICITY		FUNCTIONAL POLYCENTRICITY: DISTRIBUTION OF FLOWS		FUNCTIONAL POLYCENTRICITY: SPATIAL INTEGRATION[A]	
	MOST RECENT YEAR	PERCENTAGE CHANGE SINCE INITIAL YEAR	MOST RECENT YEAR	PERCENTAGE CHANGE SINCE INITIAL YEAR	MOST RECENT YEAR	PERCENTAGE CHANGE SINCE INITIAL YEAR
Population[1]	-0.9286	-6.65%	-	-	-	-
Employment[1b]	-0.9736	-12.18%	-0.8513	-13.88%	0.7430	39.90%
Knowledge-based sectors[2]	-1.1452	-10.28%	-0.9944	-8.67%	0.5002	23.81%
High-technology industries	-1.1547	-1.96%	-0.9907	4.61%	0.6743	32.66%
Finance, insurance and real estate	-1.2429	-13.05%	-0.9717	-9.92%	0.3993	70.79%
Knowledge-intensive services	-1.1671	-7.82%	-1.0102	-4.71%	0.2256	-46.38%
Advanced producer services	-1.1259	-17.27%	-1.0166	-22.09%	0.4855	15.82%
Creative industries	-1.1017	-11.81%	-0.9368	-18.08%	0.5215	20.97%
Knowledge-based occupations[2]	-1.0568	-13.08%	-0.8674	-13.30%	0.5049	36.53%
Management	-1.0297	-12.40%	-0.8402	-12.82%	0.4060	31.56%
Professional: business professionals	-1.0519	-15.99%	-0.9093	-14.87%	0.5045	47.26%
Professional: science and engineering professionals	-1.1073	-12.71%	-0.8523	-12.69%	0.4914	54.63%
Technical: science-technical occupations	-0.9982	-12.51%	-0.8204	-16.11%	0.6451	43.77%
Professional: health professionals	-1.2864	-4.76%	-1.0872	-1.66%	0.4438	42.66%
Technical: other health occupations	-1.0281	-15.41%	-0.8828	-13.33%	0.5717	52.70%
Professionals: education, law and social science-related professionals	-1.1452	-4.13%	-0.8990	-3.78%	0.4260	15.60%
Professional: art and culture professionals	-1.4392	14.29%	-1.2478	12.33%	0.2652	-15.27%
Activity patterns[3c]						
Work-related travel[3]	-0.8988	-2.24%	-0.8401	-11.96%	0.7548	10.37%
Male	-	-	-0.7835	-13.89%	0.7809	1.38%
Female	-	-	-0.9645	-9.41%	0.6690	2.89%
16- years	-	-	-	-	-	-
16-45 years	-	-	-0.8261	-13.89%	0.7935	0.56%
45-65 years	-	-	-0.8917	-5.17%	0.5918	-15.72%
65+ years	-	-	-	-	-	-
Less-well-educated population	-	-	-0.8449	-6.70%	0.7428	-7.84%
Medium-educated population	-	-	-0.8435	-11.99%	0.8044	22.53%
Highly educated population	-	-	-0.8710	-5.55%	0.4977	0.73%
Business travel[3]	-0.9328	-5.56%	-0.7892	-13.53%	0.4883	20.21%
Male	-	-	-0.7373	-19.08%	0.5819	23.78%
Female	-	-	-1.0718	-17.92%	0.2786	-3.80%
16- years	-	-	-	-	-	-
16-45 years	-	-	-0.7537	-26.31%	0.4192	22.54%
45-65 years	-	-	-0.8573	-11.03%	0.2874	-41.87%
65+ years	-	-	-	-	-	-
Less-well-educated population	-	-	-0.8494	-36.82%	0.8974	88.45%
Medium-educated population	-	-	-0.8253	-40.14%	0.4110	19.30%
Highly educated population	-	-	-1.0298	-15.77%	0.2244	-49.50%
Non-work-related travel[3]	-0.9132	9.13%	-0.7736	10.33%	0.7637	36.20%
Male	-	-	-0.7523	5.70%	0.7921	49.03%
Female	-	-	-0.8050	11.30%	0.7346	135.75%
16- years	-	-	-0.7881	6.47%	0.7524	8.98%
16-45 years	-	-	-0.7699	6.21%	0.8576	60.84%
45-65 years	-	-	-0.7593	18.18%	0.7397	40.79%
65+ years	-	-	-0.9621	20.93%	0.4367	-28.13%
Less-well-educated population	-	-	-0.7946	16.80%	0.7021	1.07%
Medium-educated population	-	-	-0.7780	9.76%	0.7579	50.20%
Highly educated population	-	-	-0.8210	-7.76%	0.4697	62.64%

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Education travel[3]	-0.9394	-6.63%	-1.1010	2.25%	0.7511	7.10%
Male	-	-	-1.0240	-7.38%	0.7031	-9.21%
Female	-	-	-1.1993	5.81%	0.6835	120.91%
16- years	-	-	-1.1591	11.95%	0.5202	-24.86%
16-45 years	-	-	-1.1488	-1.29%	0.6131	14.77%
45-65 years	-	-	-1.1514	3.47%	0.3663	-28.33%
65+ years	-	-	-0.6282	-2.26%	0.3265	-31.44%
Less-well-educated population	-	-	-1.0285	0.45%	0.4229	12.53%
Medium-educated population	-	-	-1.2702	8.52%	0.5996	12.22%
Highly educated population	-	-	-1.3861	-27.96%	0.2814	-13.39%
Shopping travel[3]	-0.9127	22.25%	-0.8052	15.62%	0.6166	-3.29%
Male	-	-	-0.7739	0.45%	0.5250	13.39%
Female	-	-	-0.8351	21.49%	0.6244	-2.30%
16- years	-	-	-0.8541	-16.47%	0.5698	57.36%
16-45 years	-	-	-0.7490	8.36%	0.8322	49.97%
45-65 years	-	-	-0.7950	2.05%	0.6313	10.95%
65+ years	-	-	-1.0783	56.66%	0.2143	-54.00%
Less-well-educated population	-	-	-0.8872	24.59%	0.8278	34.84%
Medium-educated population	-	-	-0.8264	18.87%	0.5368	240.83%
Highly educated population	-	-	-0.7854	-28.47%	0.3040	-16.62%
Leisure travel[3]	-0.9322	-2.47%	-0.8079	-18.34%	0.4812	7.48%
Male	-	-	-0.8049	-15.21%	0.5032	16.13%
Female	-	-	-0.8308	-20.94%	0.4615	10.75%
16- years	-	-	-0.8327	2.93%	0.8128	46.66%
16-45 years	-	-	-0.7729	-26.50%	0.4495	19.61%
45-65 years	-	-	-0.8909	-11.29%	0.4328	-3.33%
65+ years	-	-	-1.2158	11.44%	0.2947	11.33%
Less-well-educated population	-	-	-0.9163	-7.70%	0.1448	-68.88%
Medium-educated population	-	-	-0.7546	-26.69%	0.3301	-34.56%
Highly educated population	-	-	-0.9158	-23.89%	0.2492	22.40%
Social-visit travel[3]	-0.9150	2.57%	-0.8442	-7.87%	0.7416	33.65%
Male	-	-	-0.8443	-5.56%	0.8468	220.51%
Female	-	-	-0.8829	-6.05%	0.6687	30.96%
16- years	-	-	-0.9552	8.61%	0.7179	64.35%
16-45 years	-	-	-0.8436	-8.49%	0.9137	131.73%
45-65 years	-	-	-0.8666	-9.55%	0.5070	9.76%
65+ years	-	-	-0.9340	-6.25%	0.4162	-21.22%
Less-well-educated population	-	-	-0.8316	-3.97%	0.8958	36.95%
Medium-educated population	-	-	-0.8315	-14.10%	0.6831	112.54%
Highly educated population	-	-	-0.9610	-12.78%	0.4215	86.75%
Health travel[3]	-1.0268	-4.83%	-0.9614	-22.85%	0.3887	-31.24%
Male	-	-	-1.1799	10.71%	0.2650	-20.78%
Female	-	-	-0.8855	-37.00%	0.3926	-39.87%
16- years	-	-	-1.2109	-6.67%	0.6790	129.78%
16-45 years	-	-	-0.9066	-12.51%	0.4760	57.62%
45-65 years	-	-	-1.0104	-21.95%	0.4605	-26.63%
65+ years	-	-	-0.7793	-37.49%	0.2296	-57.89%
Less-well-educated population	-	-	-0.9316	-28.67%	0.4154	-44.20%
Medium-educated population	-	-	-1.1795	-5.62%	0.3515	72.73%
Highly educated population	-	-	-1.0915	-20.51%	0.2759	-37.15%

TABLE 6.1 Degree of morphological and functional (distribution of flows and spatial integration) polycentricity in Barcelona

a. Network density is calculated with the empirical modification introduced by Maturana and Arenas (2012), which improves the original version of the network density indicator proposed by Green (2007).
b. Employment data come from the census regarding the residence-to-work travel dataset provided by IDESCAT (Institut d'Estadística de Catalunya).
c. Activity patterns data come from the Enquesta de Mobilitat Quotidiana (Daily Mobility Survey) supplied by ATM (Autoritat del Transport Metropolità).

Functional polycentricity: distribution of flows

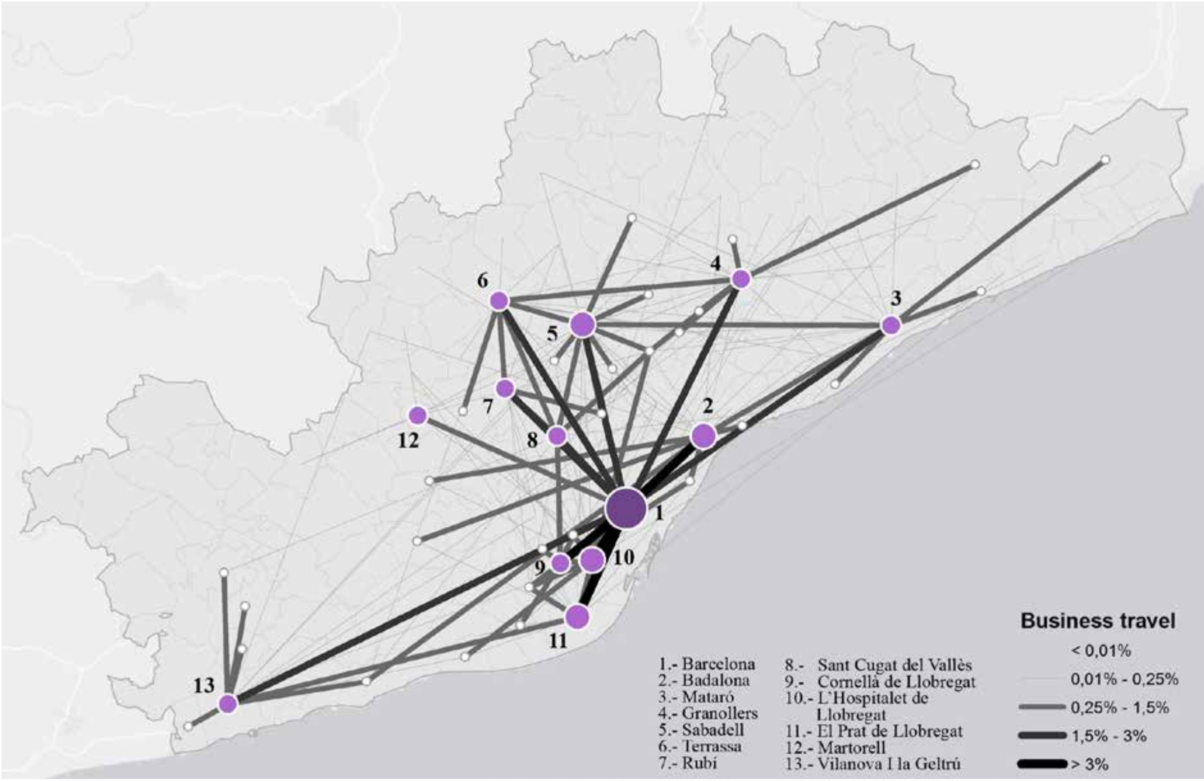
Columns 3 and 4 of Table 6.1 present the extent to which the Barcelona metropolitan region can be considered polycentric when the spatial distribution of flows (directionality) is taken into account. In this analysis, the coefficients of the rank-size regressions for the 10 most central centers and distinct networks (along with population subgroups) are generally higher (close to zero) than the rank-size regressions of the nodality scores in the most recent available year and thus, they depict a more even distribution across centers. Moreover, the distribution of flows has generally become even more polycentric since 1991. Although the distribution of centrality scores with regard to employment (-13.88%), business travel (-13.53%), and leisure travel (-18.34%) for example, has become considerably more equal between each center since 1991, the distribution of nodality scores (see column 2 of Table 6.1) for these networks has shown a more modest trend. These findings may illustrate that Barcelona is more functionally than morphologically polycentric, and even more functionally polycentric than one of the most archetypical polycentric urban regions in Europe, the Randstad, with respect to commuting, business, and leisure travel (see comparable results in Burger et al., 2014c).

In terms of the contrast among flows, the functional linkages of the total bulk of non-work-related travel (-0.77), shopping (-0.80) and leisure (-0.80) appear to have a more balanced distribution of flows than do commuting flows (-0.85). Education flows and work commutes in several knowledge-based sectors and occupations, in contrast, are more unevenly distributed, depicting a rank-size coefficient below -1.

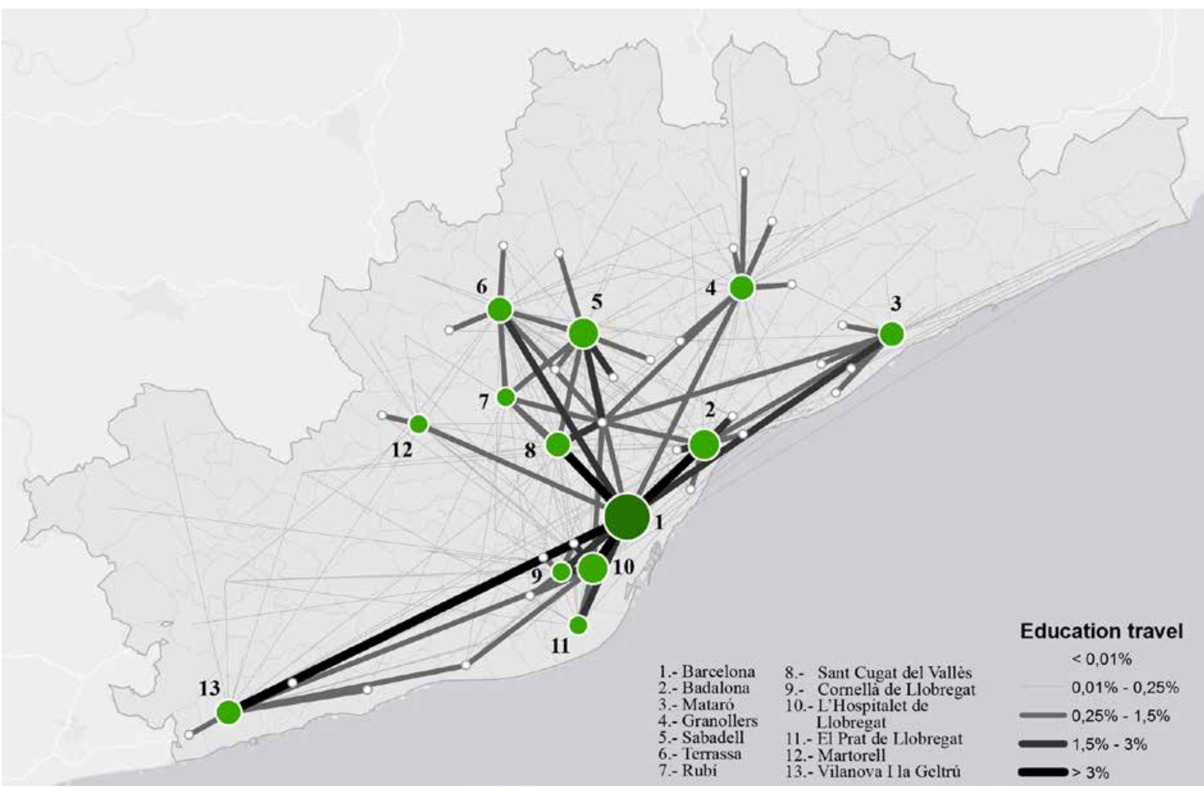
If different subgroups of population within distinct types of flows are analyzed, it is clear that individual-level heterogeneity plays a role. On average, the coefficient values of the rank-size regressions for different population subgroups are within the interval -0.80 to -1.00 in 2006, implying that moderate (<-1.00) or strong (<-1.25) levels of functional monocentricity do not occur in the Barcelona metropolitan region. Moreover, these differences among types of population subgroups lead to numerous conclusions. Whereas less-well-educated and medium-educated populations are more strongly oriented toward all of the centers, the highly educated population is relatively less multidirectional, depicting a less functionally polycentric structure. That population seems more oriented to Barcelona, an observation that is supported by the findings on the spread of knowledge-based sectors and occupations, which are relatively much more strongly clustered in Barcelona. Additionally, it seems that in general, men and younger people have a stronger polycentric orientation compared to women and older generations, who are distributed more unevenly. This could be explained by the fact that women and older generations are less prone to travel outside of their municipalities of residence.

Functional polycentricity: spatial integration

Figure 6.3 presents the spatial pattern of some of the main types of flows (business, education, shopping, and social-visit travel) among centers in 2006. The thickness of the flow illustrates the strength of the linkages (in- and out-flows) as a percentage of total interaction originating from and going to centers (to maintain the readability of the flow maps, flows involving the central city of Barcelona are not visualized). The size of the centers indicates the centrality of a center in the network, measured as the total number of in-flows that a center receives. As depicted in the flow maps (Figure 6.3a-d), the level of interconnectivity among centers can vary considerably depending on the type of flow. Whereas shopping and social-visit flows seem to remain more oriented toward centers located close to each other and their neighboring areas, the functional relationships embodied by business and education travel appear to be stronger when travel involves more distant centers.



A Business travel



B Education travel

FIGURE 6.3 Flows among centers of the Barcelona metropolitan region in 2006: business, education, shopping, and social-visit travel

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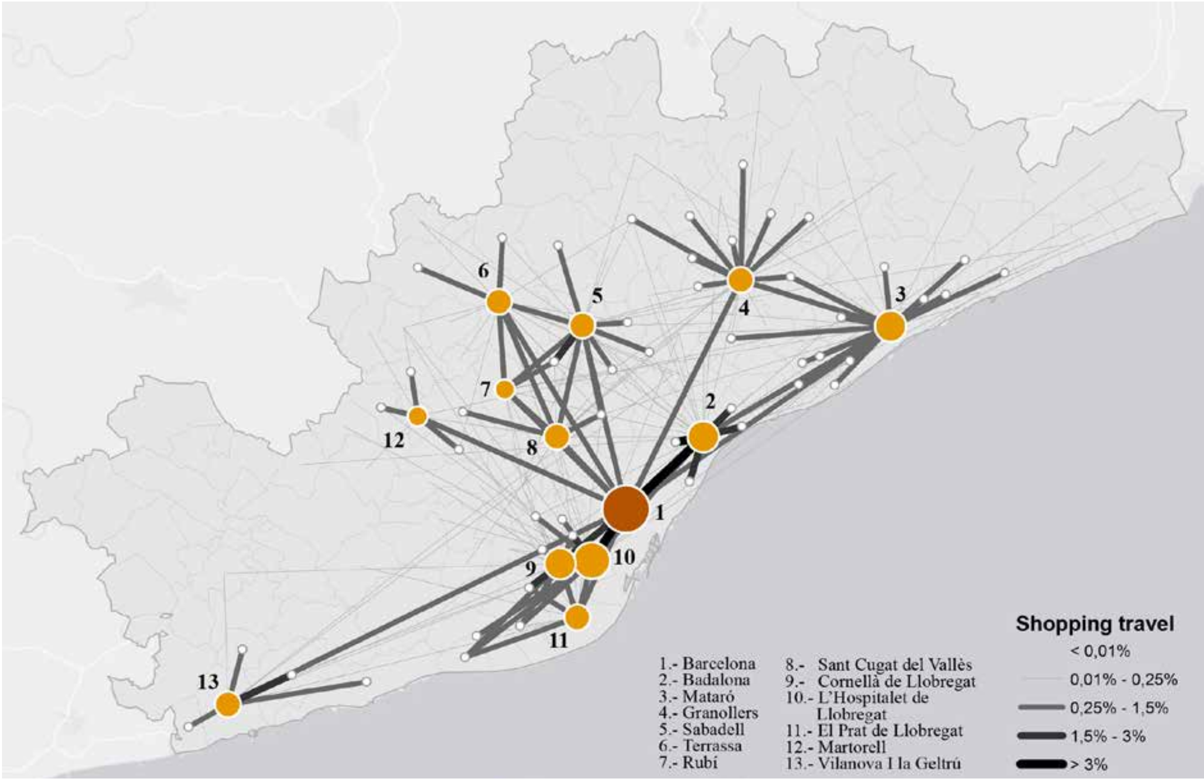
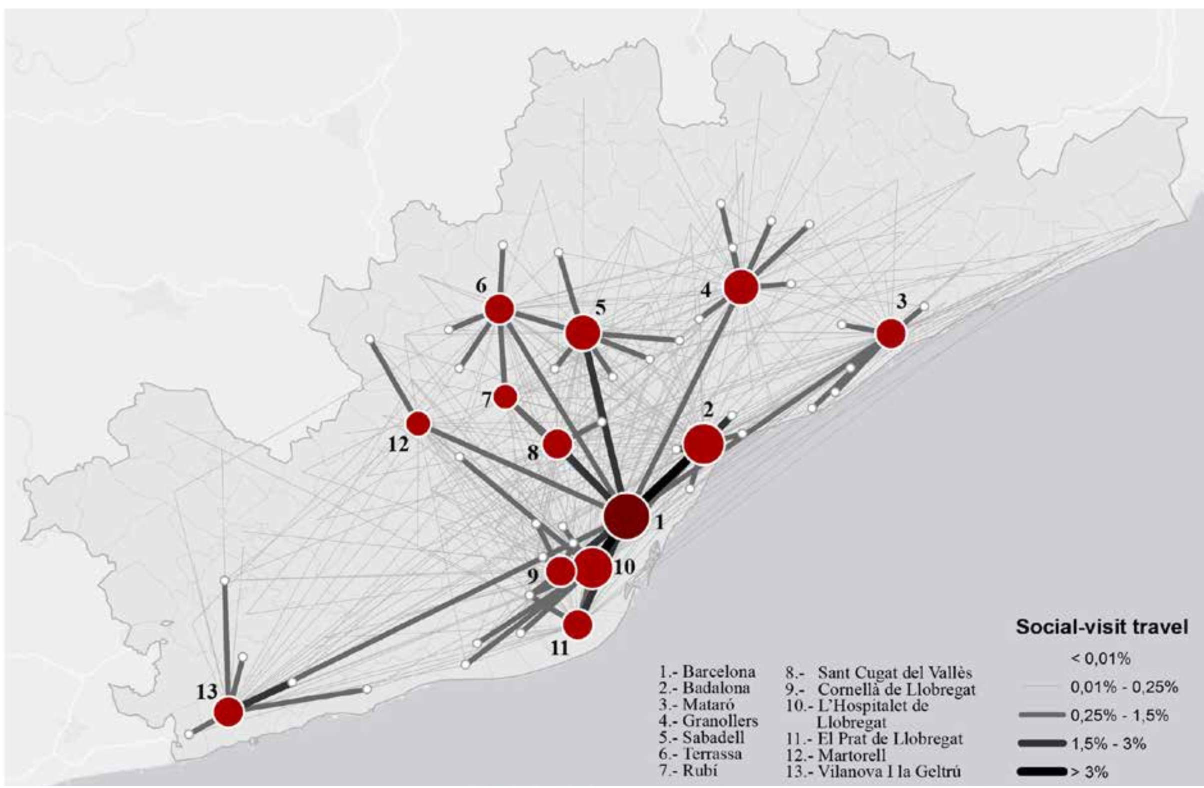


C Shopping travel



D Social-visit travel

FIGURE 6.3 Flows among centers of the Barcelona metropolitan region in 2006: business, education, shopping, and social-visit travel

Note(s): the flow illustrates the interaction (in- and out-flows) as a percentage of total interaction to and from centers (to maintain the readability of the flow maps, flows involving the central city of Barcelona are not visualized). The size of the node indicates a center's centrality in the network. The data come from the 2006 EMQ (Daily Mobility Survey) supplied by ATM (Autoritat del Transport Metropolità).

The measurement of spatial integration is described in more detail in Table 6.1 (columns 5 and 6), but now includes Barcelona itself. The results of this analysis generally stress the high degree of spatial integration among centers in the Barcelona metropolitan region, suggesting that Barcelona's metropolitan structure truly operates as a functional integrated entity. The values above 0.50 of the network density indicator for most of the analyzed functional linkages support this finding. The strongest integration among centers occurs in terms of travel-to work (0.75 in 2006), education (0.75) and social visits (0.74). At some distance, shopping (0.62), business and leisure travel (both 0.48) follow; the Barcelona metropolitan region is the least integrated in terms of health-related travel. With few exceptions, flows among centers have become stronger since 1991. Perhaps the development of new centers prompted by decentralization (see chapter 5) and the still-important role of the central city have facilitated the observed tendency toward stronger functional linkages. For instance, the substantial increase since 1991 (+70.79%) of travel-to-work flows involving jobs in financial, insurance and real estate is a case in point.

That said, the results also illustrate that the degree of spatial integration among centers in Barcelona also depends on the regional occupational and sectoral structure, along with individual-level attributes. The degree of network density with respect to sectors and occupations of the knowledge economy is perhaps relatively low (with arts and culture professionals showing the most limited integration), which may be because most of these workers live in Barcelona itself, which as we have observed is where those jobs seemed to be relatively strongly concentrated. Similar trends are observed when individual-level heterogeneity is considered. There seems to be a considerable difference between the level of spatial integration between various educational levels and age cohorts. Highly educated people account for a lower level of spatial integration than do less-educated people. People aged 16-45 are responsible for the most substantial spatial integration, which declines with age. Additionally, gender is important, with men contributing more to spatial integration.

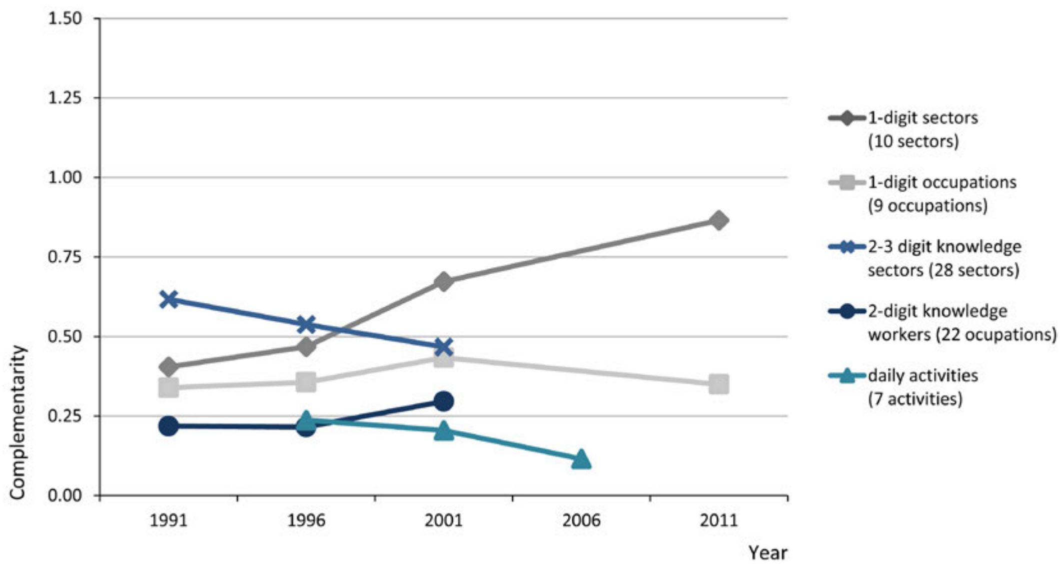
Functional polycentricity: complementarity

The development of the degree of complementarity as represented by the complementarity ratio is presented in Figure 6.4. Whereas Figure 6.4a depicts the development of complementarities among centers with regard to their sectoral and occupational profile and the type of daily activities undertaken there in the 1991-2011 period, Figure 6.4b adds more nuances to this study on the development of potential complementarities among centers in the Barcelona metropolitan region by excluding the central city (Barcelona) from the analysis.

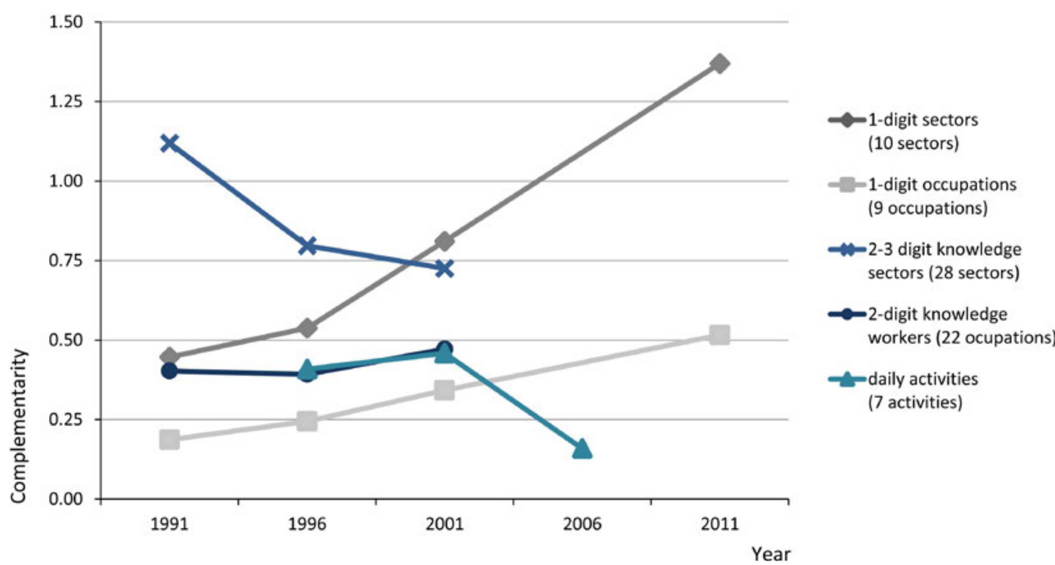
At first glance, the results illustrate that the extent of the potential complementarity in the regional sectoral structure among centers was much higher than that of the regional occupational structure in 1991 and that of the distribution of daily activities (resembling urban functions) in 1996 (see Figure 6.4a). This indicates that the Barcelona metropolitan region's centers had much more similar occupational and urban-functions profiles than sectoral profiles. When Barcelona's effect on the degree of complementarity is controlled, the results show that there is indeed a higher potential for complementarity, which is also largely explained by the contribution of the regional sectoral structure (see Figure 6.4b).

A more detailed analysis, now considering the development of potential complementarity since 1991, leads to the following findings. General sectoral complementarity has sharply increased between 1991 and 2001 (+114.14%). In contrast, the overall extent of complementarity in knowledge sectors has decreased considerably between 1991 and 2001 (-24.32%). In terms of occupations, complementarity has increased slightly (+3.27%) since 1991, although it has declined during the most recent period.

For knowledge workers, the increase was +35.62% during 1991-2001. Interestingly, these findings highlight that over the 20-year period studied, Barcelona metropolitan region's centers have become more different from each other and thus, it can be argued that their relationships have become more complementary than competitive. Moreover, it seems that a particular division of labor is being developed in terms of the knowledge-based occupations, but not in terms of sectors. This is consistent with those studies (e.g., Duranton and Puga, 2002, 2005) that have predicted the rise of a new division of labor in metropolitan areas caused by the profound transformations in internal firms' organization. However, the lack of data for 2001-2011 has prevented this research from obtaining findings that are more robust.



A Among centers (central city included)



B Among centers (central city excluded)

FIGURE 6.4 Development of the extent of (potential) complementarity among centers (with and without considering the central city) in Barcelona, 1991-2011

Perhaps the above findings can be partly explained by the polycentric development and the emergence of new centers since 1991, in accordance with the findings of chapter 5. The polycentric pattern in Barcelona, like elsewhere, has essentially been inherited because centers that mainly specialized in manufacturing activities (such as Sabadell and Terrassa) were incorporated into the metropolitan area dominated by the central city of Barcelona. Moreover, this pattern has been influenced by recent decentralization trends of employment and urban functions away from Barcelona, resulting in the formation of the centers of Rubí, Martorell and Sant Cugat del Vallès, among others. Those centers' role may explain why the potential complementarity in knowledge sectors (for example) has rapidly decreased. Since 1991, some of the knowledge sectors previously concentrated in Barcelona (e.g., high-technology industries or even the financial, insurance and real estate, and advanced producer services sectors) have been decentralized to those new centers in a concentrated manner, which has resulted in sectoral profiles that are more similar (35.15% more similar, as shown in Figure 6.4b). However, the rise in complementarity in terms of occupations may suggest that the jobs that were decentralized are different from the jobs that remain in the central city.

These urban dynamics also appear to be one of the most plausible causes for the diminishing differentiation among centers with regard to the type of activities performed in centers (e.g., working, shopping, studying, etc.). The potential for complementarity in urban functions among centers (excluding the central city) has sharply diminished in the 1996-2006 period (-61.18%), and thus it seems that many activities have decentralized to the new centers. Below, a more detailed analysis of the centers' profiles is presented to identify specific complementary and competitive relationships among the centers in the Barcelona metropolitan region.

Current patterns of complementarity in sectors

The figures included in this and the following subsections require careful interpretation. They graphically display the relative position and associations between centers and the categories of the city profiles (e.g., sectors, occupations, or daily activities). The intersection of the axes of this 2-D plot defines the origin (0.0) that indicates the centers' average profile. Two centers that are located close to each other in the plot have a relatively similar profile. The same interpretation holds for the association between sectors, occupations, or daily activities. For example, if two sectors are located close to each other, then these sectors are more or less similarly distributed over the centers. The primary difficulty arises from the distances between centers and sectors, occupations, or daily activities because those distances are not based on chi-squares distances. The reason for this problem is that all of the centers have an impact on the location of, for example, an occupation; conversely, all of the occupations determine the location of a center. The appropriate rule to interpret these associations is that in general, centers and occupations/sectors/activities will be close when they are more associated with each other (the observed value for this pair of points in the contingency table is larger than the expected value), whereas they tend to be located at a distance when they are less associated with each other.

Figure 6.5 presents the associations between centers and knowledge-based sectors in 2001. This research has also explored the relationships between centers and all of the economic sectors in 2011, but in the interest of space, these results are not presented; they are available upon request. It seems that a general pattern of complementary and competitive relationships among centers can be depicted by examining the relationships obtained from these two analyses. Centers originating from decentralization seem to both complement (e.g., Martorell and El Prat de Llobregat) and compete (e.g., Sant Cugat del Vallès) with the central city. They complement the central city when they specialize in sectors related to industry and transportation, whereas they compete when they allocate high-order business and services sectors. Centers arising out of incorporation-fusion (e.g., Sabadell and L'Hospitalet de Llobregat) appear to compete with Barcelona when all economic sectors are considered. In contrast, when only knowledge sectors are considered, incorporated-fused centers located geographically closest to the central city of Barcelona (e.g., Badalona and L'Hospitalet de Llobregat) seem to complement instead of compete with Barcelona.

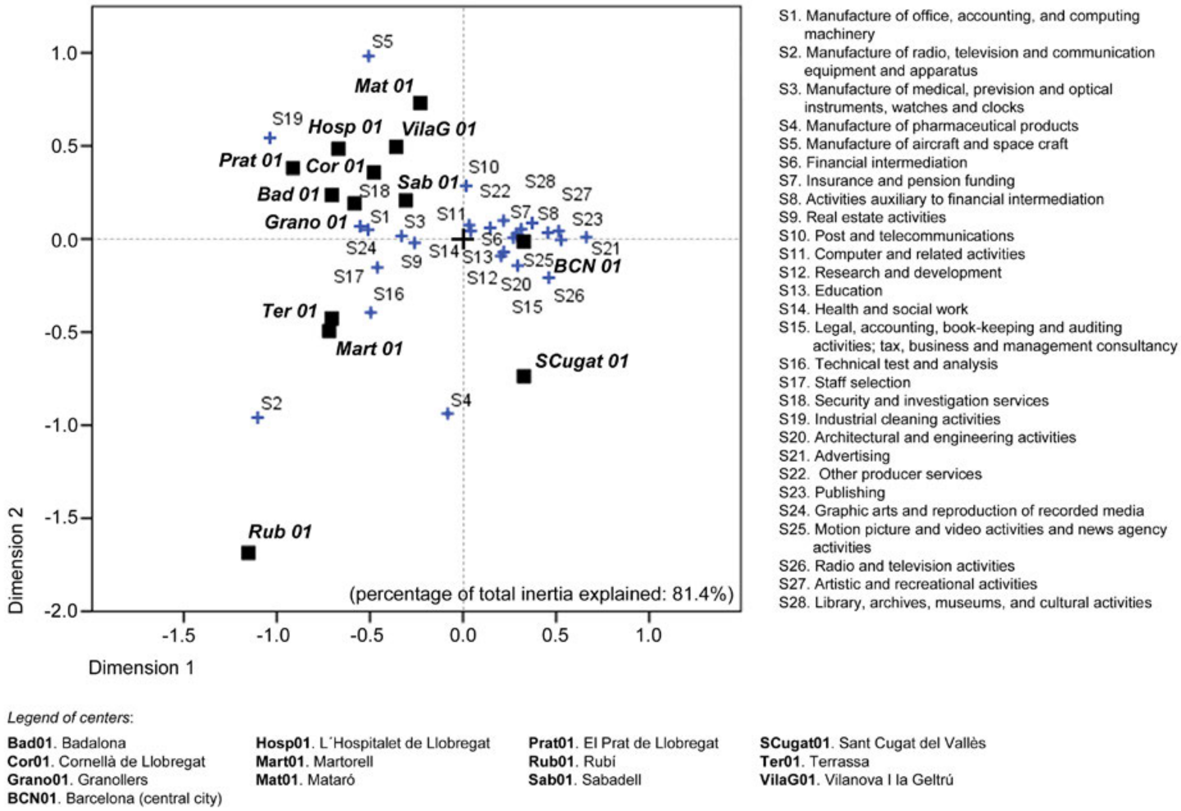


FIGURE 6.5 Complementary and competitive relationships among centers in Barcelona: knowledge-based sectors (2-3 digits) in 2001

More specifically, the general complementarity and competitiveness among centers is exemplified as follows. Rubí contributes most to total inertia in 2001 (i.e., is the most specialized center) because it is located furthest from the origin (0.0). This center shares a strong position in 'manufacture of radio, television and communication equipment and apparatus' and 'manufacture of pharmaceutical products' with Sant Cugat del Vallès, Martorell, and Terrassa, which also have a relatively distinct sectoral profile. Other sectors that are exclusively linked to one center (thus providing the greatest contribution to total inertia) include 'manufacture of aircraft and spacecraft' and 'industrial cleaning activities', which are associated with Mataró and El Prat de Llobregat-L'Hospitalet de Llobregat-Badalona, respectively. In contrast, the central city of Barcelona has an average sectoral profile because of its location relatively closer to the origin (0.0). Barcelona has a particularly dominant position in certain financial, insurance and real estate sectors ('insurance and pension funding' and 'activities auxiliary to financial intermediation') and unsurprisingly, in sectors related to creative industries (e.g., 'publishing', 'artistic and recreational activities' and 'library, archives, museums, and cultural activities'). Moreover, it shares strong positions in 'radio and television activities' and 'legal, accounting, book-keeping and auditing activities; tax, business and management consultancy' with Sant Cugat del Vallès. More specifically, Sant Cugat del Vallès' profile in advanced producer services and creative-industry activities, together with Sabadell's profile in knowledge-intensive services sectors, most closely resemble Barcelona's sectoral profile. Sabadell shares, for example, a dominant position in 'post and telecommunications', 'computer-related activities', and 'health and social work' with Barcelona, although it is important to emphasize that because these knowledge-intensive services sectors lie relatively close to the origin (0.0), they seem to be more evenly spatially distributed across the centers.

TOC

Current patterns of complementarity in occupations

Figure 6.6 depicts the relationships between centers and knowledge-based occupations in 2001. The associations between centers and a general classification of occupations in 2011 have been examined but as before, in the interest of space their results are not presented; they are available upon request. As a benchmark observation, it can be argued that the previous pattern of associations among centers in relation to sectors can also be generally found in terms of occupations. More specifically, Sant Cugat del Vallès' profile in occupations, which is closely associated with 'directors and managers' and 'technicians, professionals, scientists, and intellectuals', most closely resembles Barcelona's profile. Moreover, it shares with Barcelona a strong position in 'business chief executives', 'professionals in natural sciences and health with a 4-5 year college degree', and 'professionals in education with a 4-5 year college degree'. Unsurprisingly, Barcelona is also relatively more associated with most high-order knowledge workers ('writing, creative and performing artists', 'professionals in law', 'professionals in physical, chemical, mathematical and engineering sciences with a 4-5 year college degree', and 'professionals in business organization, social sciences and human sciences'). In contrast, other decentralized centers (such as Martorell and Cornellà de Llobregat) or centers adjacent to Barcelona (such as El Prat de Llobregat and L'Hospitalet de Llobregat) have a relatively dominant position in those knowledge occupations that are much less closely linked to Barcelona, such as 'physical, chemical and engineering technicians', 'accounting, financial and other related service technicians', and 'natural sciences and health technicians'. Finally, it can also be noted that the centers of Mataró, Sant Cugat del Vallès, Badalona, Rubí, L'Hospitalet de Llobregat, and El Prat de Llobregat contribute most to total inertia in 2001 because they are located furthest from the origin (0.0).

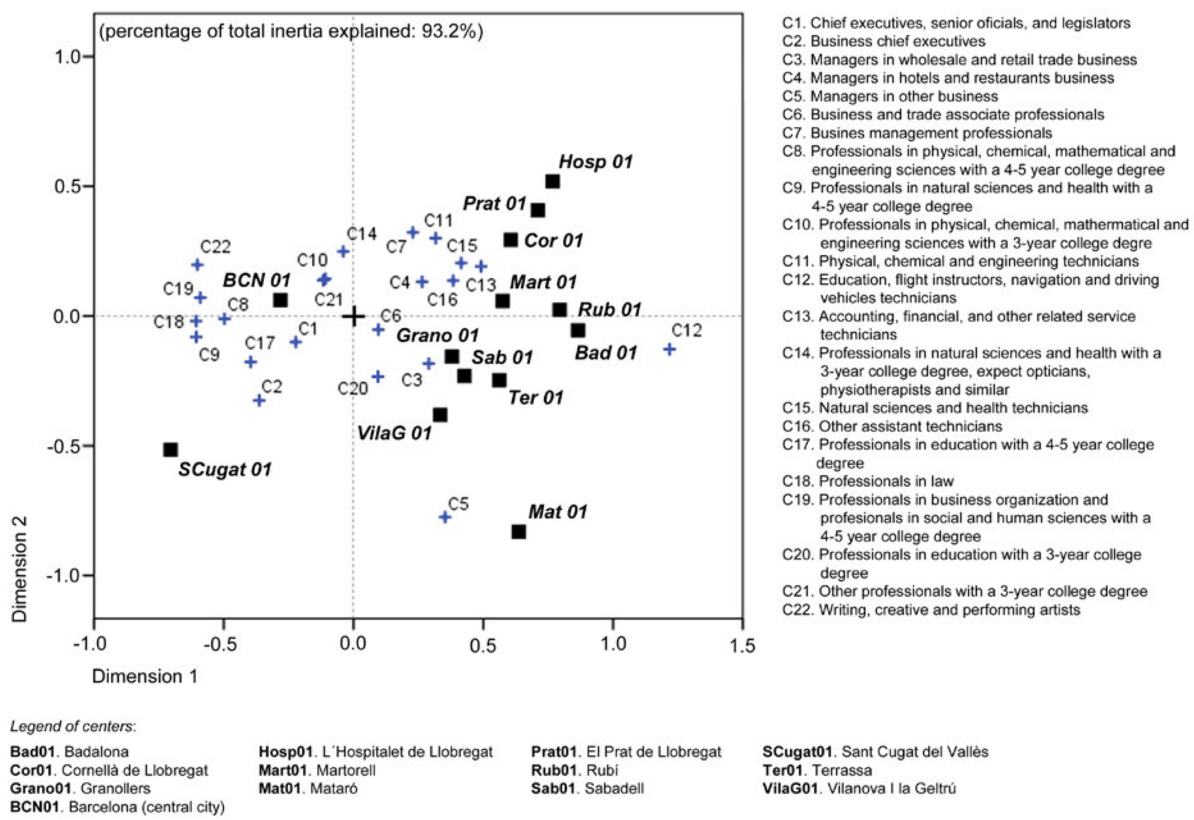


FIGURE 6.6 Complementary and competitive relationships among centers in Barcelona: knowledge-based occupations (2 digits) in 2001

Current patterns of complementarity in daily activities

Figure 6.7 shows the associations between centers and daily activities (resembling urban functions) in 2006. The relatively close location of many activity patterns and urban functions (e.g., education, leisure, and social visits) to the origin (0.0) indicates that they seem to be relatively evenly spread over the centers. This may point to the existence of some competition rather than complementarity among centers in terms of urban functions, which is consistent with the declining trend of the extent of complementarity since 1996 (-51.60%) depicted in Figure 6.4a. However, other urban functions appear to be more exclusively linked to some centers and therefore, have a more uneven spatial distribution across centers. This is the case for health activities, which are more related to centers such as Barcelona, L'Hospitalet de Llobregat, and Sabadell, which allocate general hospitals and community health centers. Moreover, Barcelona unsurprisingly shares a dominant position in business activities with Sant Cugat del Vallès. Finally, it can be argued that Barcelona is very closely associated with work activities, which is as expected given that most jobs are still concentrated there.

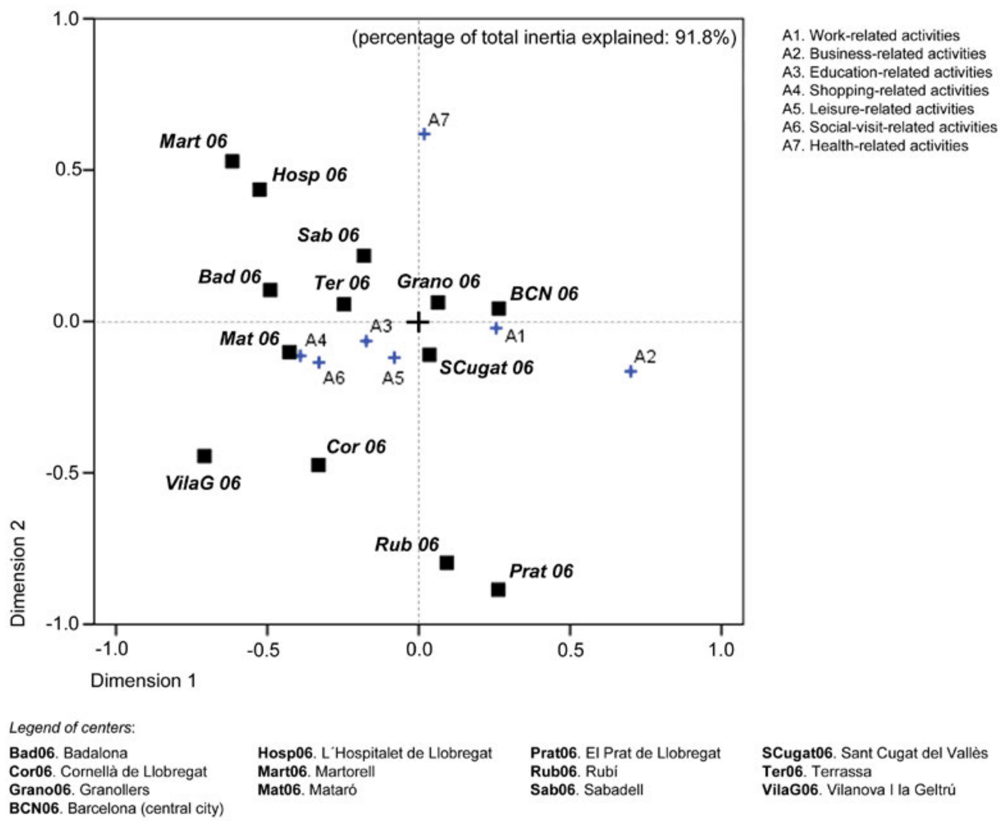


FIGURE 6.7 Complementary and competitive relationships among centers in Barcelona: daily activities (resembling urban functions) in 2006

§ 6.6 Conclusion and discussion

This chapter has aimed not only to quantify Barcelona's internal metropolitan structure and development since 1991 but also to discuss that structure in relation to polycentric development policies. The main research question was the extent to which the metropolitan structure of Barcelona can be considered polycentric from a morphological and functional perspective and how that structure can inform planning practice. This chapter's research approach has addressed the primary issue related to the literature on measuring polycentricity, namely, the scale-dependent interpretation of polycentricity, by uniting the intra- and inter-urban approaches to measure polycentricity in a single framework. More specifically, this study renews the measurement of intra-urban polycentricity by considering the absolute (nodality) and the relative (centrality) importance of centers, along with the level of spatial integration as well as complementarity among centers. The research approach used in this study to quantify the degree of morphological and functional polycentricity has also incorporated two refinements to obtain broader conclusions on the extent to which a metropolitan area is polycentric. First, it has explored the spatial organization of different types of urban networks (e.g., business, leisure, social-visit, and health travel) that are not identical ('multiplexity') and the variety in these spatial interaction patterns that can be attributed to differences among people or firms ('individual-heterogeneity'). Second, it has considered the regional occupational and industrial (sectoral) structure in the polycentricity measurement, particularly with respect to knowledge-based occupations and sectors because of their contribution to regional economic development and their valuable insights into planning practice.

The empirical analysis has illustrated that although measurement of the degree of polycentricity is function- and individual-level dependent, four key research findings emerged. First, Barcelona is (morphologically speaking) only a slightly polycentric metropolitan region compared to other metropolitan regions worldwide that are characterized as archetypical polycentric because Barcelona's central city continues to play a dominant role in certain high-order occupations and sectors, although the nodality or absolute importance among centers has become increasingly more equal since 1991. Second, centers' centrality (relative importance in flows) reveals a more even spatial distribution than in terms of nodality or absolute importance among centers, and that more even relative importance among centers has increased over time. Third, the functional linkages among centers appear to be moderately strong and centers have become more interdependent since 1991, thus indicating that the Barcelona metropolitan region can be truly perceived as a functionally integrated metropolitan entity. Fourth, development of the extent of complementarity among centers from 1991-2011 highlights that centers have become more sectorally and occupationally distinct, entailing more complementary instead of competitive relationships among them. Moreover, a division of labor appears to be developing with regard to knowledge workers, revealing that centers are increasingly distinguished by occupational—not sectoral—specialization. However, the potential for complementarity in urban functions among centers from 1996-2006 has decreased, requiring centers to become more similar to each other in terms of the daily activities undertaken there; that said, this could be attributable to the not-unnatural trajectory toward polycentricity through decentralization. Consequently, it can be argued that both morphological and functional polycentricity exists in the Barcelona metropolitan region, but the region is more functionally than morphologically polycentric because of the stronger empirical evidence of a more balanced distribution of flows, spatial integration, and complementarity.

Implications for planning

The patterns emerging from this study of the metropolitan spatial structure of Barcelona and its development also stimulate further discussion in the context of polycentric development policies. In particular, it could inform planning related to the understanding, governance implications and expectations of polycentric development. Four main points can be highlighted in this regard. First, given the empirical evidence for a certain level of polycentricity and development in that direction, the polycentric development strategy for the Barcelona metropolitan region appears to be both appropriate and feasible because it is not rowing against the tide.

Second, the research approach and findings of this chapter could improve the understanding of polycentric development in spatial plans and other policy documents. For instance, the 2010 Barcelona Metropolitan Territorial Plan, which was discussed in chapter 4, identifies the roles played by centers in establishing non-hierarchical relationships aimed at either encouraging or discouraging regional cooperation to increase economic competitiveness. However, the 2010 Barcelona Metropolitan Territorial Plan assumes roles based exclusively on centers' size, which is completely at odds with the nature of a polycentric networked system, which features a disconnection between size and function. This chapter provided evidence-informed knowledge to more accurately choose centers' roles to either encourage or discourage regional cooperation. Based on the study of complementarities among centers, it identified, for example, not only the role played by Barcelona as a 'Global Gateway' for global advanced producer services and highly skilled professional networks to enhance economic competitiveness but also other important roles for secondary centers, such as Sant Cugat del Vallès in accountancy and business consultancy activities or El Prat de Llobregat in transportation, storage, and logistics activities.

Third, the strong functional linkages among centers with regard to several types of flows, which show that the Barcelona metropolitan region operates as a functional integrated entity, could also clarify the debate about the appropriate territorial scale upon which to apply a polycentric development strategy and the appropriate scale upon which to base a metropolitan government. For example, this knowledge of functional interdependencies seems to support the definition of a polycentric development strategy and the establishment of a powerful metropolitan government on the territory that corresponds to the area envisioned by the 1966/1974 *Pla Director de l'Àrea Metropolitana de Barcelon*a over other territorial visions of Barcelona's metropolitan realm (see chapter 3) because it would be easier to achieve the (assumed) positive agglomeration externalities related to polycentricity.

Fourth, the fact that morphological polycentricity is less present than functional polycentricity in Barcelona may indicate that policymakers could pay more attention to functional polycentricity to adequately develop policies to build economic competitiveness, social equity, and environmental sustainability. In other words, the research findings could note that regardless of whether there is a link between polycentric development and performance, it may be easier to foster better performance in the Barcelona metropolitan region by focusing on centers' functional aspects. For instance, the strong evidence for spatial integration among centers and the overall development of more complementary relationships among centers could strengthen support for a tangential model of transportation networks among centers to reduce congestion and increase the efficiency of the public transportation system. The reason is that the presence of these two aspects of functional polycentricity is a prerequisite for encouraging individuals' flows among and to centers.

These expectations aroused by polycentric development indicate a call for further examination of the association between polycentricity and performance to bring the estimated effects of this relationship to architects, planners, and policymakers in an evidence-informed form. Chapter 7 aims to do this by conducting research on polycentricity and its link to the co-location of jobs, people, urban functions, and choice of travel mode.

PART 4 Polycentricity and Performance

7 Polycentricity, the co-location hypothesis and travel mode choice

§ 7.1 Introduction

The link between the built environment and travel behavior continues to be a widely debated topic among transportation, planning, and urban economy scholars. The literature's primary theoretical surveys emphasize the lack of consensus on the relationship between built environment and travel (e.g., Ewing and Cervero, 2001, 2010; Stead and Marshall, 2001) because empirical research often leads to contradictory outcomes. One controversy addresses the influence of an unfolding polycentric metropolitan layout on mobility patterns. More precisely, the question is whether the development of multiple urban centers next to a central city core allows the reorganization of mobility patterns in a more socially and environmentally friendly manner. The rather scarce literature available on the relationship between polycentricity and mobility patterns has examined two important and related topics. The first topic is whether a polycentric development allows for the co-location of jobs and households, leading to shorter commutes and commuting times. The periodic readjustment of the location of firms and households and the associated positive effects in trip lengths and durations is known as the 'co-location hypothesis'. It is however, unclear whether that hypothesis holds in a polycentric urban context (see, e.g., Aguilera, 2005; Gordon and Lee, 2014). The second topic is whether polycentricity affects individual decisions to use transportation modes that are more environmentally friendly modes. With respect to this second topic, the debate has also not led to conclusive findings. For instance, whereas Song et al. (2012) have found that a polycentric structure increases the usage of public transportation, Schwanen et al. (2001) drew contradictory conclusions.

This chapter aims to shed new light on these discussions by answering two specific research questions (see section 2.5 in chapter 2). The first research question is as follows: To what extent do people living in a center conduct their daily activities in that or another center? In addition, to what extent do people who do not live in a center conduct their daily activities in the center that is closest to them? Therefore, this chapter examines whether the development of multiple centers in the Barcelona metropolitan region influences the co-location of people, jobs and urban amenities, thus leading to reduced trip distances and times. The second research question is as follows: To what extent does polycentricity encourage sustainable travel mode choices, and how can its effects be realized in planning practice? Thus, this chapter also explores whether polycentricity could play a role in changing individual decision about the use of more sustainable travel modes such as public transportation, walking or bicycling.

Answering these questions allows an assessment of whether polycentricity has the assumed positive effects on the performance of metropolitan areas, particularly with respect to people's mobility patterns (see section 2.3 in chapter 2). This assessment provides empirical evidence that allows us to infer planning strategies that help realize the (assumed) benefits of polycentricity in planning practice (see Figure 1.3 in the introduction to this thesis). In particular, the estimated effects (e.g., average marginal effects or elasticities) of the link between polycentricity and performance could be provided to architects, planners, and policymakers in an evidence-informed manner aimed at creating a set of policy recommendations. These policy recommendations may be of great interest for the makers of the 2010 Barcelona Metropolitan Territorial Plan to deliver on its objectives regarding, for example, the development of public transportation to foster environmental sustainability (see Generalitat de Catalunya, 2010).

In exploring these questions, this chapter will introduce several conceptual and methodological novelties. Conceptually, it builds a more comprehensive and systematic empirical framework to attempt to unify the existing, fragmented empirical research on the advantages of polycentricity, thereby achieving broader conclusions about its effects. Instead of a broad definition of a polycentric urban system that does not identify its centers, thus hampering an accurate analysis of the effects of polycentricity, this study builds on the set of centers identified in chapter 5. Moreover, this study adopts the conceptual approach to the link between polycentricity on the intra-urban scale and the performance of metropolitan areas proposed in chapter 2 (see Figure 2.2) to examine the effects of polycentricity. More specifically, this chapter will consider three distinct dimensions of a polycentric spatial configuration that play a role in the development of agglomeration benefits in a metropolitan area: the size of centers, the (geographic) proximity to centers, and the aggregate size of centers through their integration. In addition, it considers a wide range of trip purposes, whereas most of the studies in the literature have focused on commuting. Methodologically, this chapter applies a combination of econometric techniques that has not previously been used in the literature on polycentricity and travel mode choice. In particular, it applies the combination of multinomial logit modeling to analyze travel mode choice with multilevel modeling to account for the fact that explanatory variables are measured at different levels of aggregation.

The rest of the chapter is organized as follows. Section 7.2 reviews the existing literature on the relationship among polycentricity, the co-location hypothesis, and travel mode choice. Section 7.3 discusses the reasons for discrepancies among research findings on polycentricity and defines the main challenges involved in building a more comprehensive and systematic framework to examine polycentricity's effects. Section 7.4 presents the data, variables and method used in this study. Section 7.5 explores the validity of the co-location hypothesis. Section 7.6 presents the findings from the travel mode choice analysis. Finally, section 7.7 sets out the main conclusions and discusses how the benefits of polycentricity can be realized in planning practice.

§ 7.2 The link between polycentricity, the co-location hypothesis and travel mode choice

The relationship between urban form and people's daily trip patterns in metropolitan areas has been contextualized in the transition from monocentric to polycentric spatial configurations. Building upon the literature, Figure 7.1 schematically presents theoretical conceptions of how mobility patterns vary in monocentric and polycentric metropolitan areas. Moreover, Figure 7.1 shows how these various mobility patterns are linked to the performance of metropolitan areas, building on the literature on agglomeration economies (benefits) that is explained in chapter 2 (see section 2.3). These theoretical conceptions will guide the part of this section that are aimed at reviewing the scholarly approaches to studying how monocentricity or polycentricity interacts with trip lengths, trip durations and travel mode choice.

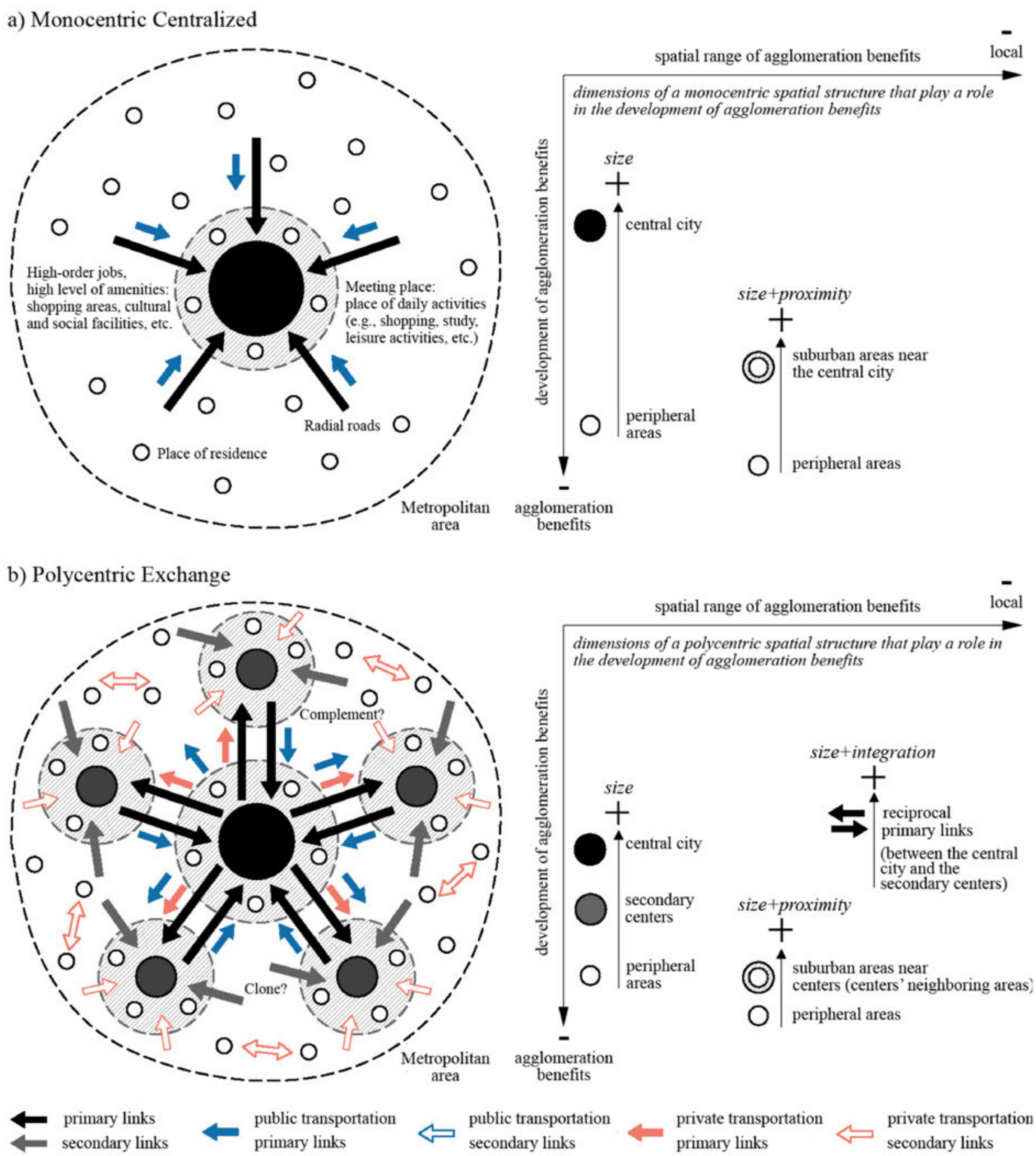


FIGURE 7.1 Mobility patterns and performance of monocentric versus polycentric metropolitan areas studied in the literature

Own elaboration based on the contributions of Van der Laan (1998), Bertaud (2002), and Schwanen et al. (2003).

Polycentricity and the co-location hypothesis

The first theoretical approach that explains trip patterns within metropolitan areas is the monocentric model coined by the New Urban Economics; that model is based on the well-known bid-rent theory (see also chapter 5). This approach is a classic model in which most employment (e.g., high-order jobs) and urban functions (e.g., shopping and leisure areas) are heavily concentrated in the central city of the metropolitan area. The resulting trip pattern is a monocentric-centralized pattern that follows radial transportation axes, thus allowing people to travel from the suburbs to work in the central city core, where they also pursue other activities (see Figure 7.1a). Individuals' choice to live in the suburbs follows the bid-rent theory, which assumes that as the distance to the central city increases, the rising cost of traveling to the city should be compensated by lower rents, which are translated into lower land intensities. This implies that households choose where to live by trading off the value of access to the central city against the cost of housing. Consequently, individuals bid to locate their households close to the central city in a monocentric situation to economize on travel costs, although the shorter the daily trips to the central city, the higher the land value and housing costs.

The second conceptualization of mobility patterns within metropolitan areas is related to the rise of a polycentric model that evolves from the original monocentric structure. This perspective has also been situated within the New Urban Economics framework, in which the transition to a polycentric metropolitan area is explained by the decentralization of jobs and urban functions from the central city because of the appearance of strong centrifugal forces or agglomeration diseconomies, as noted in chapter 5 (section 5.2).

With this decentralization of both firms (jobs) and urban functions, along with their concentration in certain suburban areas, thus forming multiple centers, a new relationship of locational tradeoff between centrality and travel costs has been formulated by the polycentric New Urban Economics models. Essentially, these models have predicted that the emergence of several centers will enable individuals to choose from multiple job and daily activity locations, allowing greater proximity between residences and meeting places (workplaces and places of daily tasks) and avoiding agglomeration costs that are related to the monocentric model, such as congestion and land prices (e.g., Dubin, 1991; White 1988, 1999; Yinger, 1992; Zax and Kain, 1991). These predictions of the New Urban Economics models have been empirically substantiated by several studies. For instance, Sasaki (1990) and Sasaki and Mun (1996) highlight that people tend to locate their households within or close to these new centers to reduce travel costs. Fujita and Owaga (1982) theoretically illustrate that more centers appear when transport costs and population growth increase, and McMillen and Smith (2003) have empirically corroborated that the number of centers in metropolitan areas increases with population size, commuting costs, and older housing stock.

Since the 1980s, and within this context of the polycentric New Urban Economics models, a group of researchers led by Peter Gordon have developed a set of empirical studies showing that decentralization leads to a more efficient mobility pattern as the inhabitants of polycentric metropolitan areas spend less time traveling and make shorter trips compared the inhabitants of monocentric areas (e.g., Gordon and Wong, 1985; Gordon et al., 1988, 1989a, 1989b, 1991). This argumentation is known in the literature as the co-location hypothesis.

Essentially, Gordon and his colleagues rely on the idea that the concentration of activities (work and non-work-related ones) in monocentric configurations induces congestion because of such configurations' typical radial (suburb-to-central-city) trips. In this regard, households and firms in polycentric metropolitan areas seek to avoid additional travel costs (distance and time) by changing their location (place of residence, place of work, or both) and find new locations in areas that are less congested. This may cause individuals either to travel shorter distances or to spend less time traveling by using routes that are less congested, which induces more complex and diversified mobility patterns between a multitude of origins and destinations, as shown in Figure 7.1b.

In this way, daily trip patterns may follow an 'exchange' pattern (Schwanen et al., 2003; Van der Laan, 1998). This stylized polycentric mobility pattern assumes that primary relationships are reciprocal between the central city and the new centers (denoted as secondary centers in Figure 7.1b) because they can be complementary in terms of economic profiles and urban functions and thus, many residents of secondary centers either work or perform other daily activities in the central city (centralized commuting), whereas many residents of the central city travel to secondary centers and their neighboring suburban zones for both work and non-work purposes. This polycentric mobility pattern could also enable residents in newly developed centers to increasingly benefit from the advantages of agglomeration (e.g., greater accessibility to jobs and amenities) that develop locally because of the centers' size, which may increase as decentralization continues. Additionally, it enables residents in the suburban zones surrounding these new centers to benefit more than residents of more-distant suburban areas from the centers' agglomeration economies thanks to their greater proximity. The evolution of this polycentric mobility pattern therefore could be translated into a higher likelihood that people living in or close to these new centers will do their daily activities (e.g., working, shopping, etc.) at or near their place of residence because they do not have to travel to the central city and thus, they may enjoy a shorter trip distance and time.

The empirical results obtained by subsequent studies, however, do not reveal consistency in the research findings about whether the rise of polycentric structures originating from decentralization results in lower trip lengths and trip durations or whether they instead lead to at least a stabilization of travel costs over time. On the one hand, some authors found that the decentralization of jobs and urban functions to new centers has led to reduced travel costs (trip distance and time) for people living beyond the central city. Decentralization has been associated with shorter average trip distances in both North American (Cervero and Wu, 1997; Crane and Chatman, 2003; Kim, 2008; Wachs et al., 1993) and European (Aguilera et al., 2009; Gutiérrez and García-Palomares, 2007) metropolitan areas. Residents of suburban areas, in addition, had the shortest trips, whereas residents of the central city had the longest ones (Gordon and Lee, 2014). Other studies note that households, firms, and other organizations effectively respond to changes in travel requirements by locating themselves in places that either maintain or reduce travel times (Anas, 2011; Levinson and Kumar, 1994; Levinson and Wu, 2005). Finally, it has been shown that on average, people working in a center beyond the central city spent less time traveling than those working in the central city (Lee, 2006b; Sultana, 2000).

On the other hand, another body of literature has rejected the co-location hypothesis, advancing two findings that are contradictory in comparison with the previous findings. First, suburbanites' average trip time increased due to the job-housing imbalance observed in new suburban centers (Cervero, 1989b, 1996b; Cervero and Landis, 1992; García-Palomares, 2010). Second, the average trip time (Cervero and Wu, 1998; Ewing, 1997; Lowe, 1998) and distance (Aguilera, 2005; Aguilera and Mignot, 2004; Naess, 2006) increased for those suburban residents because most people living in centers worked outside of them, and the majority of centers' jobs are filled by people who live further away from centers.

Polycentricity and travel mode choice

In addition to conceptualizing the relationship between polycentricity and changes in travel costs by considering the decentralization trajectory to polycentric metropolitan areas, the current literature has explored how individuals' travel mode choices have been influenced by the decentralization of people, jobs, and urban functions. In a monocentric situation (Figure 7.1a), scholars have suggested that the suburb-to-central-city trips, organized in a radial pattern oriented toward the central city, are favorable for public transit (Bertaud, 2002). The main reason for this finding could be that the substantial size of a large city that fosters a wider range of agglomeration benefits—e.g., the greater presence of several types of jobs and urban amenities in the central city—supports public transit because people from suburban areas have a single orientation.

In a polycentric configuration arising out of decentralization (Figure 7.1b), however, the relationship between daily trip patterns and public transit is less self-evident because individuals living in suburban areas can choose between multiple destinations (central city and new developed centers). Moreover, according to the co-location hypothesis, many households may be located closer to their daily activities. Scholars have debated whether this relocation has also induced a modal shift from public transportation and slow modes of transportation such as walking or bicycling to private transportation. Evidence appears to show that most suburb-to-central-city trips are still made by public transportation, whereas trips between new centers and their suburbs are made by private transportation, but it has remained unclear—as the studies explained below illustrate—whether trips between centers (central city and new centers developed in the suburbs) encourage public transit use and whether this could increase public transportation's market share in the metropolitan area.

One perspective found in the literature is that decentralization has led to a shift from public to private transportation. Cervero (1989a), Cervero and Landis (1992) and Cervero and Wu (1997, 1998) note that suburbanization in the San Francisco Bay Area has resulted in workers traveling similar trip distances at faster speeds, switching from the predominant use of public transit to significant car usage. Similar effects have also been found, for example, in Melbourne, where the share of public transportation trips dropped from 30% to 10% and walking trips dropped from 36% to 13% after suburbanization (Bell, 1991). The same applies to Toronto, where most trips generated by suburban office centers were made by car, although suburban centers located near public-transit stations generated 20% more public-transit trips than did centers that were further from the central city (Pivo, 1993). Other scholars have illustrated that greater proximity (access) to the central city increases the likelihood that people will use transportation modes that are more sustainable (García-Palomares, 2010; Naess, 2005, 2010; Naess and Sandberg, 1996). In addition, the negative association between polycentricity and choices of travel modes that are more sustainable has been depicted by studies that have classified urban systems into distinct patterns of monocentric and polycentric urban forms based on the patterns of flows among their constituent parts. Schwanen et al. (2001, 2002, 2004) and Dieleman et al. (2002) emphasize that polycentric urban systems and suburban locations have generally encouraged car use for both work- and non-work-related travel in the Netherlands, whereas public transportation and slow modes are more common in urban systems' central city cores.

Another perspective found in the literature suggests a positive relationship between polycentricity and travel mode choice. Some studies reveal that polycentric urban systems arising out of decentralization do not reduce public transportation's market share (Anas, 2011; Bolotte, 1991). They are even associated with decreased car usage (especially for trips between the centers that comprise polycentric systems (Aguilera et al., 2009)) and a higher use of public transit and walking in areas close to these centers (Naess, 2005). Similarly, Vega and Reynolds-Feighan (2008) show that people living in Dublin's central city or close-by suburban centers are less likely to use private cars than workers commuting to further-flung centers. Song et al. (2012), find that people living or working in either the regional central city of Shenzhen or subregional centers are more likely to use public transportation compared to people living or working in other areas.

These studies also suggest that the effect of polycentricity on travel mode choice is mediated not only through investment in new public transportation infrastructure but also through local characteristics of the urban areas involved and more precisely, their built environment attributes (e.g., density, land-use mix, urban amenities, etc.). These factors may be associated with studies in transport geography that consider how the built environment is related to travel mode choice. Here, the built environment can be defined as the full array of an urban area's morphological and locational characteristics, and the study of the built environment's influence on travel mode choice is important because it may shed more light on how polycentricity is connected to travel mode choice.

The built environment and travel mode choice

The key inference made by scholars to conceptualize the link between the built environment and travel mode choice is that denser cities or neighborhoods enhance the use of public transportation, walking, and bicycling instead of private transportation for both work- and non-work-related trips (e.g., Cervero, 1996a, 2002; Frank and Pivo, 1994; Schwanen et al., 2004). This is because the greater spatial concentration of houses and jobs is accompanied by a greater diversity (mix) of land use, which means that urban facilities are closer to households. In addition, better accessibility to work (jobs), amenities and transit (e.g., Bento et al., 2005; Commins and Nolan, 2011; Kockelman, 1995) leads to higher use of sustainable transport modes. Greater proximity to the central city (e.g., Cervero, 1996a; Commins and Nolan, 2011; García-Palomares, 2010; Naess, 2005) and a more suitable urban design such as park-and-ride facilities or the presence of a well-developed sidewalk infrastructure (e.g., Commins and Nolan, 2011) have a similarly positive effect on the use of public transit, walking and bicycling.

However, the accumulated empirical evidence has revealed the built environment's ambiguous influence on travel mode choice. Frequently, the effect of some of the local morphological and location characteristics of urban areas turns out not to be statistically significant (e.g., Schwanen, 2001; Susilo and Maat, 2007). Sometimes, the direction of the relationship is the opposite of what was expected (e.g., Bento et al., 2005). Even if these built environment characteristics are significant, their effect on public transportation use, walking and bicycling often is fairly modest (e.g., Cervero and Kockelman, 1997).

§ 7.3 The reasons for discrepancies among research findings on polycentricity

This brief review of previous empirical research illustrates that the debates on the relationship among polycentricity, the co-location hypothesis and travel mode choice, along with the built environment's impact on travel mode choice, have not yet been settled. In part, the discrepancies in outcomes can be explained by conceptually and methodologically different approaches to the concept of polycentricity on the one hand, and the application of different research methods on the other hand.

Various approaches to polycentricity

Conceptualizations of polycentric mobility patterns

The first issue that explains the discrepancies in study outcomes relates to the conceptualization of the driving forces that underlie polycentric development. Many studies have only considered the assumption that the transition to polycentric configurations has been exclusively driven by decentralization (see Figure 7.1b), and this assumption does not cover the incorporation-fusion of (once) distinct cities (see chapter 5). Consequently, centers are characterized by their location (e.g., close-by and outlying centers) relative to the central city (e.g., Aguilera, 2005; Cervero and Wu, 1998). However, as Figure 7.2 shows, trip patterns will be somewhat different when polycentricity arises out of the incorporation-fusion of existing centers because these centers tend to be characterized, for example, by a substantial city size and the presence of higher-order amenities; in addition, they host and have the ability to attract economic activity. This means that a polycentric 'cross' pattern (see Figure 7.2a) will be more prevalent (Schwanen et al., 2003; Van der Laan, 1998). The latter pattern may also offer a major source of potential for complementarities among the centers of a metropolitan area instead of a similar profile. In this case, the polycentric mobility pattern can be defined as 'cross-exchange' or 'decentralized' (Schwanen et al., 2003; Van der Laan, 1998) because of the reciprocal primary links between the central city and the secondary centers (see Figure 7.2b).

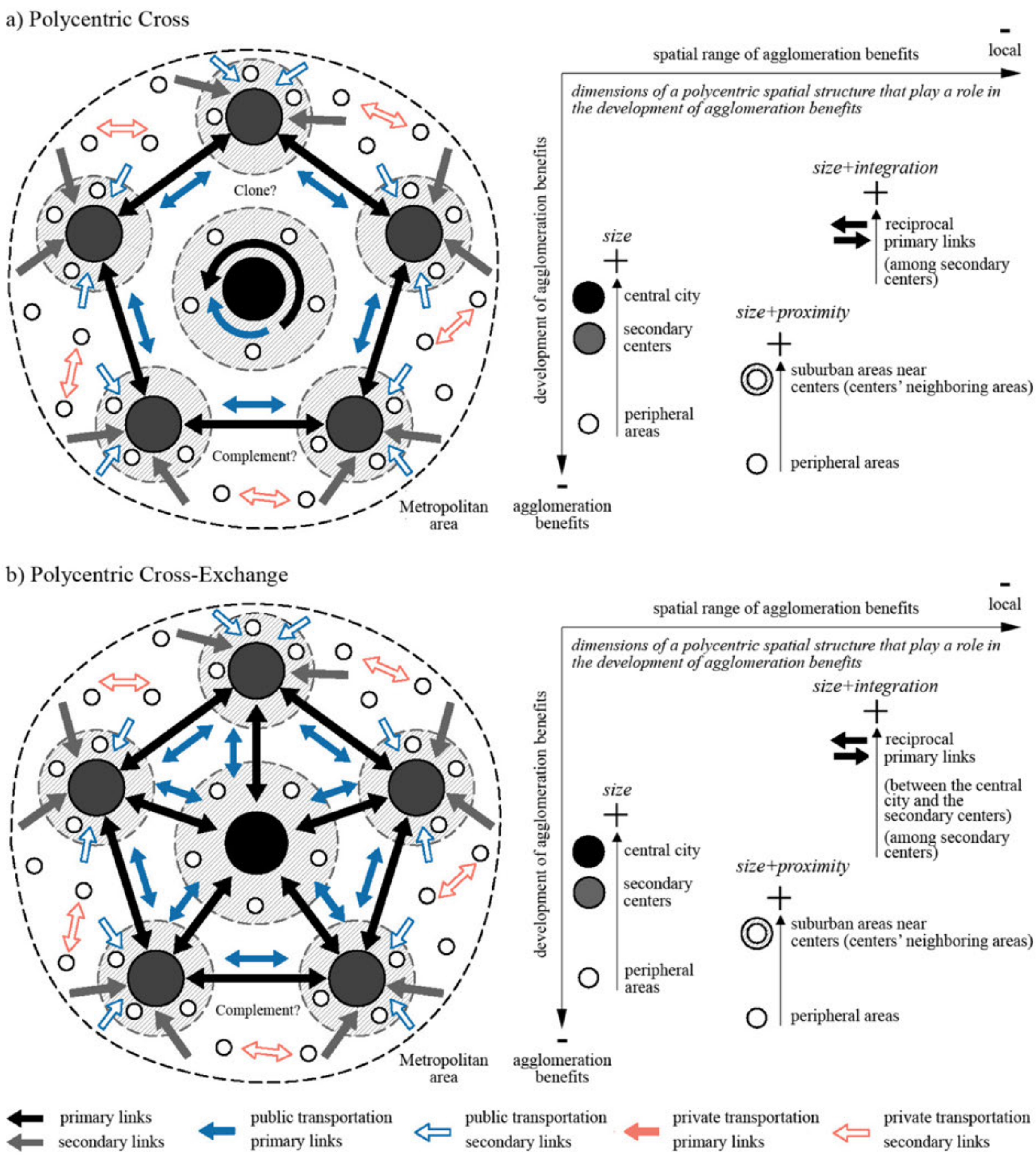


FIGURE 7.2 Mobility patterns and performance of polycentric metropolitan areas arising out of the incorporation-fusion trajectory

Own elaboration based on the contributions of Van der Laan (1998), Bertaud (2002), and Schwanen et al. (2003).

It is important to include the incorporation-fusion mode of polycentricity because that mode reveals which mobility pattern within a polycentric urban system could be the most sustainable. The point is that the development of agglomeration benefits in a polycentric metropolitan area varies substantially depending on the centers' origin (see also Figure 2.3 in chapter 2). It can then be argued that the 'cross-exchange' polycentric pattern (Figure 7.2b) is a slightly more sustainable mobility pattern than the 'cross' polycentric pattern (Figure 7.2a) and considerably more sustainable than the 'exchange' polycentric pattern associated with centers that arise out of decentralization (Figure 7.1b), which are discussed above. This can be supported by three arguments, each of them building upon a different dimension of a polycentric spatial configuration that, as chapter 2 (see section 2.3 and Figure 2.2) noted, play a role in the development of agglomeration benefits in a metropolitan area.

First, the larger size of centers that arise out of incorporation-fusion (see chapter 2 and 5 for a more detailed explanation) leads to greater urbanization (economies) advantages—e.g., greater access to several types of jobs, along with amenities and a diversity (mix) of land use—for households located in those centers. Therefore, the residents of this type of center are more likely to experience shorter trip distances and travel times. Moreover, they are more likely to use public or slow modes of transportation—i.e., walking and bicycling—instead of private transportation. The greater concentration of several types of jobs and amenities that results from the urbanization advantages of centers arising out of incorporation-fusion greatly increases the relative competitiveness of public transit and slow modes because the advantages of using private transportation (e.g., shorter travel times) decrease (e.g., due to congestion) when people enjoy greater accessibility to the places where they perform their daily activities (e.g., working, shopping, etc.).

Second, the greater distance-decay effects of centers that arise out of incorporation-fusion (see theoretical explanations in chapter 2 and empirical substantiation in chapter 5) mean that households and firms located near this type of center not only will benefit more from this proximity but also will be more dependent on their greater access to these centers' agglomeration benefits. This greater dependence leads to more socially and environmentally sustainable suburb-to-centers trips in the polycentric mobility patterns associated with centers that arise out of incorporation-fusion than in the mobility pattern associated with centers that arise out of decentralization. For instance, public transportation could become more competitive than cars in a 'cross' and 'cross-exchange' polycentric pattern (see secondary links regarding public transportation in Figures 7.2a-b) because more people are encouraged to travel from locations near centers to centers to perform their daily activities given the agglomeration advantages of 'incorporated-fused' centers over 'decentralized' centers.

Third, the stronger linkages both among the 'incorporated-fused' centers and between those centers and the central city mean that incorporated-fused centers better exploit their aggregate urban size, leading to the development of greater agglomeration economies. In part, this development of agglomeration benefits that results from the aggregate size of centers through the strength of their integration occurs because centers that arise out of incorporation-fusion are more complementary (see Champion, 2001:664-665), and complementarity fosters both interaction and integration (see the reciprocal primary relationships among secondary centers in Figures 7.2a-b). It can then be argued that households and firms located in these 'spatially integrated' centers enjoy additional advantages. For example, households located in one of these 'spatially integrated' centers not only enjoy a greater accessibility to several types of jobs and amenities resulting from the urbanization advantages of the center in which they are located but also enjoy a greater accessibility to the agglomeration benefits of the other 'integrated' centers (which is a major cause of the stronger integration). This could provide an even greater reduction in residents' travel costs (trip distance and travel time), and increasingly fostering the competitiveness of public transportation as more people are encouraged to travel between centers. The development of agglomeration benefits when centers exploit their aggregate size according to the strength of their integration also explains why a 'cross-exchange' mobility pattern is more sustainable than a 'cross' polycentric mobility pattern. Because a 'cross-exchange' polycentric mobility pattern also assumes the existence of complementary relationships between the central city and the secondary centers (compare Figure 7.2a with Figure 7.2b), centers associated with this mobility pattern will be even more likely to exploit their aggregate urban size, thus leading to greater agglomeration benefits.

Consideration of the two driving forces behind polycentric development and their related travel patterns could therefore shed more light on the empirical research on polycentricity's effects on travel mode choices and the co-location of people, jobs, and urban functions.

Reconciling empirical approaches to polycentricity

A second issue that explains the studies' diverging results relates to the existence of two approaches to examining the effects of polycentricity. It seems that these approaches must be reconciled to obtain answers that are more conclusive. On the one hand, a small body of literature has characterized urban systems as either monocentric or polycentric and subsequently compares their trip distances, trip times, and mode choices. In elaborating the characterization of the urban systems, this approach uses distinct analytical procedures. For instance, urban systems have been classified based either on their location within a country (e.g., Dieleman et al., 2002; Gordon and Wong, 1985; Schwanen et al., 2002; Susilo and Maat, 2007)—for example, whether they are located in a well-known polycentric urban region such as the Randstad (Susilo and Maat, 2007)—or on the functional typology of an urban system (Schwanen et al., 2001, 2003, 2004), based on the classification proposed by Van der Laan (1998). However, these contributions are limited because their definition of urban systems might be too general to address the relationship between polycentricity and travel patterns because they do not identify the centers that shape a polycentric spatial configuration. For instance, the classification of urban systems based on the functional links between central core and suburbs (e.g., Schwanen et al., 2003:416) could hamper an accurate analysis of the spatial matching among people, urban amenities, and jobs within centers (co-location hypothesis) because it does not account either for the fact that certain suburban areas have already become centers through decentralization or for the fact that the urban system has become more polycentric because of the incorporation-fusion of new centers, as discussed above. Additionally, this type of research could complicate the empirical analysis of the relationship between polycentricity and travel patterns based on considering the three distinct dimensions of a polycentric spatial configuration that play a role in the development of agglomeration benefits in a metropolitan area to build, as chapter 2 argued, a more comprehensive and systematic empirical framework to attempt to unify the fragmented empirical research on the advantages of polycentricity. For example, this type of research does not enable scholars to empirically substantiate whether the effects of proximity to centers or the effects of the size of centers plays a significant role in individuals' travel mode choice and in particular, in encouraging individuals to engage in more intensive use of travel modes that are more sustainable.

On the other hand, the second approach starts either by identifying various spatial subdivisions (e.g., central city, inner and outer suburbs) within a metropolitan area (Gordon et al., 1989a; Levinson and Kumar, 1994) or by identifying a metropolitan area's centers by using local knowledge (Bell, 1991; Naess, 2005; Song et al., 2012), by examining the spread of employment (e.g., Lee, 2006b; Vega and Reynolds-Feighan, 2008), or by exploring the functional relationships among urban areas (e.g., Aguilera, 2005). Polycentricity's impact on travel patterns is subsequently analyzed. For instance, the average trip distance and average trip time of people who work in the central city is compared with those of people working in suburban centers and other locations (e.g., Aguilera, 2005; Cervero and Wu, 1998; Gordon and Lee, 2014; Lowe, 1998); alternatively, trip distance and time are compared for those who work in the central city versus those who work in the inner and outer suburbs (e.g., Crane and Chatman, 2003; García-Palomares, 2010). Although this second approach does focus on a more appropriate geographical scale, it does not account for how centers have become united in a polycentric framework: i.e., through decentralization or through incorporation-fusion. As was explained in chapter 2 (see sections 2.2 and 2.3) and chapter 5, this distinction is important because polycentricity's (dis)advantages could depend on these two types of centers. Thus, my approach to studying the effects of polycentricity on co-location and travel mode choice will incorporate this dimension, thereby generally building on the second approach that starts from the identification of centers to the subsequent examination of their effects on individuals' travel behavior. For that reason, I build on the method of identifying centers that is proposed in chapter 5.

Various research methods and data

Various research methods may also explain the lack of conclusive answers in the debate about the relation between polycentricity and travel behavior. Most scholars have used individuals as a basic unit of analysis while linking other variables at higher geographical levels (e.g., census tracts) to this first-level data for individuals to then apply either standard binary logit (e.g., Cervero, 2002; Vega and Reynolds-Feighan, 2008) or multinomial logit (e.g., Dieleman et al., 2002; Schwanen et al., 2001; Song et al., 2012) models to examine the link between polycentricity (and/or the built environment) and mode choice. The use of standard logit models cannot take into account the fact that data have been aggregated at different geographical levels (e.g., individuals nested within census tracts), and thus, these models cannot control for within (e.g., between individuals) and between (e.g., across census tracts) grouping effects. This inaccurate treatment of microlevel variations leads to reduced variation and standard errors in these logit models and therefore, may bias the estimation results in that the significance levels of the included determinants may be overestimated (Snijders and Bosker, 2012). In addition, the use of standard logit models for hierarchical data violates the basic assumptions of independent measurements such as spatial autocorrelation (Raudenbush and Bryk, 2002). For instance, observations at the lowest geographical scale (e.g., individuals) clustered in the same higher geographical unit (e.g., census tracts) share locational effects and are commonly more similar to each other than to individuals living in other areas, indicating that in general, the decision-making process (e.g., which travel mode to choose) is not random. The econometric literature has proposed addressing these estimation problems by estimating variations within and between groups by extending the random part of the models. However, with the exception of Schwanen et al. (2004), there are no studies of the link between polycentricity and travel mode choice that adequately control for microlevel variations in the empirical analysis of such relationships.

A second issue that hinders the comparison of such studies' findings is the use of different types of data on travel. Many studies rely on aggregate data by taking spatial units such as municipalities or communes as their unit of analysis (e.g., Camagni et al., 2002; García-Palomares, 2010). Other authors, however, employ disaggregated individual-level data (e.g., Schwanen et al., 2004; Susilo and Maat, 2007). In this regard, contradictory findings may arise because the aggregate analysis does not control either for variations among individuals or for factors that affect their travel behavior (e.g., educational level attained, sex, household composition, age—see Burger et al., 2014b). Furthermore, aggregate data analysis suffers from the risk of ecological fallacy (see Ewing and Cervero, 2010; Schwanen et al., 2003, 2004). That is, such an analysis assumes spatial units are the subjects that act (e.g., number of cars per person or percentage of households with children in a municipality) on travel behavior, whereas in reality, the actors are individuals.

Another issue related to the data is that most studies have only explored commuting, not other trip purposes related to non-work travel (e.g., shopping and leisure trips). The consideration of these other trips, which typically represent approximately 60% of travel (Bertaud, 2002), would have added important nuances as those few studies that have considered them separately have shown (e.g., Dieleman et al., 2002; Gordon et al., 1988, 1989a; Levinson and Kumar, 1994). Non-work- and work-related travel even seem intertwined in complex multi-purpose trips; for instance, Gordon et al. (1988) have found that trip cost savings (shorter trip distance and less travel time) attributable to polycentric development facilitates the growth of non-work trips (e.g., family, personal, and recreational trips).

The challenges of examining the effects of polycentricity

The discrepancies in research findings on the relationship among polycentricity, travel mode choice, and the co-location of people, jobs and urban amenities call for further examination using an appropriate research approach that addresses these conceptual and methodological issues. Such an approach should account for the various pathways (decentralization and incorporation-fusion) to the formation and unification of centers in a polycentric spatial configuration. The method developed in chapter 5, which identifies centers by examining both the spread of employment and the functional relationships among urban areas, is this type of more comprehensive, systematic approach to defining polycentricity. The consideration of the three distinct dimensions of a polycentric spatial configuration that play a role in the development of agglomeration benefits in a metropolitan area—namely, the size of centers, the (geographic) proximity to centers, and the aggregate size of centers through their integration (see section 2.3 in chapter 2)—could also contribute to building a more comprehensive, systematic empirical framework to examine the effects of polycentricity. The point is that these dimensions are significant for the conceptualization of which polycentric mobility pattern could be understood as the most sustainable (see Figures 7.1-7.2). The translation of these three dimensions of a polycentric metropolitan structure into an empirical framework means examining the sustainability effects of being located in or oriented toward centers, of being located close to these centers, and of interaction patterns among centers. Therefore, it seems that three statements on when polycentric development leads to more sustainable travel behavior can be made:

1. Size of centers: Polycentric development is beneficial when people living in centers or performing their daily activities in these centers are more likely to use public transit and slow modes of transportation than if they do not live in centers or are not carrying out their activities in these centers.
2. Size of and proximity to centers: Polycentric development is beneficial when living close to centers leads to more sustainable travel mode choices than living further away.
3. Size of and interaction among centers: Polycentric development is beneficial when trips among centers are usually made via public transportation.

Finally, taking work and non-work-related travel into account and employing a model framework to allow the use of hierarchical data without biased estimation results also appear as a sound basis for empirical research that answers the two research questions formulated in this chapter:

1. To what extent do people living in a center conduct their daily activities in that or another center? In addition, to what extent do people who do not live in a center conduct their daily activities in the center that is closest to them?
2. To what extent does polycentricity encourage sustainable travel mode choices, and how can its effects be realized in planning practice?

The next section details the data, variables and methods used to address these questions.

§ 7.4 Research approach: data, variables and methods

Data and variables

To address the research questions posed, this chapter draws on mobility data derived from the census and the Daily Mobility Survey (*Enquesta de Mobilitat Quotidiana* (hereafter, 'EMQ')). The mobility data obtained by the census provides exhaustive information about the flows of the population (above 16 years of age) between all municipalities in the Barcelona Metropolitan Region for the purpose of travel-to-work trips. Consequently, it is possible to accurately know the origin and destination of the total number of employed people that a municipality sends to and receives from other municipalities. The dataset that considers the total bulk of transportation modes is provided by *Institut d'Estadística de Catalunya* (hereafter, 'IDESCAT') for the years 1991, 1996 and 2001, whereas the disaggregate dataset that considers various transportation modes is supplied by *Instituto Nacional de Estadística* (hereafter, 'INE') for 2001 only. Recently, the 2011 census data have become available due to a joint elaboration between IDESCAT and INE. However, this 2011 census edition presents severe limitations that do not allow a similarly exhaustive analysis of residence-to-work travel at the municipal-level in a similar fashion as is possible for the 2001, 1996, and 1991 editions (see, e.g., footnote 15 of chapter 5 and footnote 24 of chapter 6 for more details).

The EMQ elaborated by Barcelona's Metropolitan Transportation Authority (*Autoritat del Transport Metropolità* (hereafter, 'ATM')) was designed to collect comprehensive information for the attributes of all trips (e.g., trip purposes, transportation modes) made by an individual during a week (7 consecutive days). Since 1996, ATM has carried out the EMQs every 5 years. This research selected the EMQ for 1996 and 2001 because the 2011 edition is unavailable and the 2006 edition contains a less accurate examination of the territory of the Barcelona metropolitan region.[26]

The survey questionnaires of the 1996 and 2001 EMQ were randomly distributed to residents of all of the 164 municipalities in metropolitan Barcelona, defining 250 and 402 distinct survey zones, respectively. Whereas the survey questionnaire of the 1996 EMQ was answered by 26,457 people, who recorded having originated 274,452 trips, the 2001 EMQ one was completed by 30,740 individuals, who providing information about approximately 342,975 trips. The questionnaire model of these travel surveys provides detailed information about the trip makers' purposes and modes of transport, which enable aggregation into work and non-work trips and into private transportation, public transportation, and walking-bicycling. More specifically, the 2001 EMQ defines 12 distinct trip purposes and 16 modes of transport, whereas the 1996 EMQ reports 14 purposes and 17 modes. Furthermore, the trip information provided by the 1996 and 2001 EMQ allows the classification of non-work-related trips into 5 categories: shopping, leisure, education, social-visit, and health travel. In this chapter, it is desirable to focus on the travel behavior of individuals who can undertake trips relatively independently at a time for which it would be possible to compare the mobility data provided by the census. For that reason, this study selected from the EMQ survey for 1996 and 2001 individuals aged 16 years and older. The 1996 and 2001 EMQ data on non-work trips together with the 1991, 1996 and 2001 census data, which exhaustively define work trips between municipalities, were used to analyze the co-location hypothesis.

26 Compared to previous editions, the 2006 EMQ is extended to the entire Catalan territory. However, this resulted in the 2006 EMQ offering information only about travel on trips generated in municipalities with more than 50,000 inhabitants (18 out of 164 municipalities).

For the analysis of travel mode choice for work and non-work trips, the 2001 EMQ data are used. The 2001 EMQ data also contain information on a variety of individual-specific characteristics. These trip-maker attributes at the individual-level (level-1), combined with other variables related to the built environment attributes and polycentricity measured at municipal-level (level-2), define the research design of this study to examine mode choice, as summarized in Figure 7.3. In this analysis, the trip-maker factors are operationalized first by each individual's gender (male or female). Second, this study considers the subjects' age by using age cohorts (6 categories), professional status (7 categories), and educational level (3 categories). In addition, this work considers the subjects' household types by defining three continuous variables: the overall number of household members, the number of infants and young children (below 4 years), and the number of older children and teenagers (between 4 and 16 years). Finally, this research uses five more individual variables: drivers' license (yes or no), car ownership (yes or no), motorcycle license (yes or no), motorcycle ownership (yes or no), and the duration of the activity.

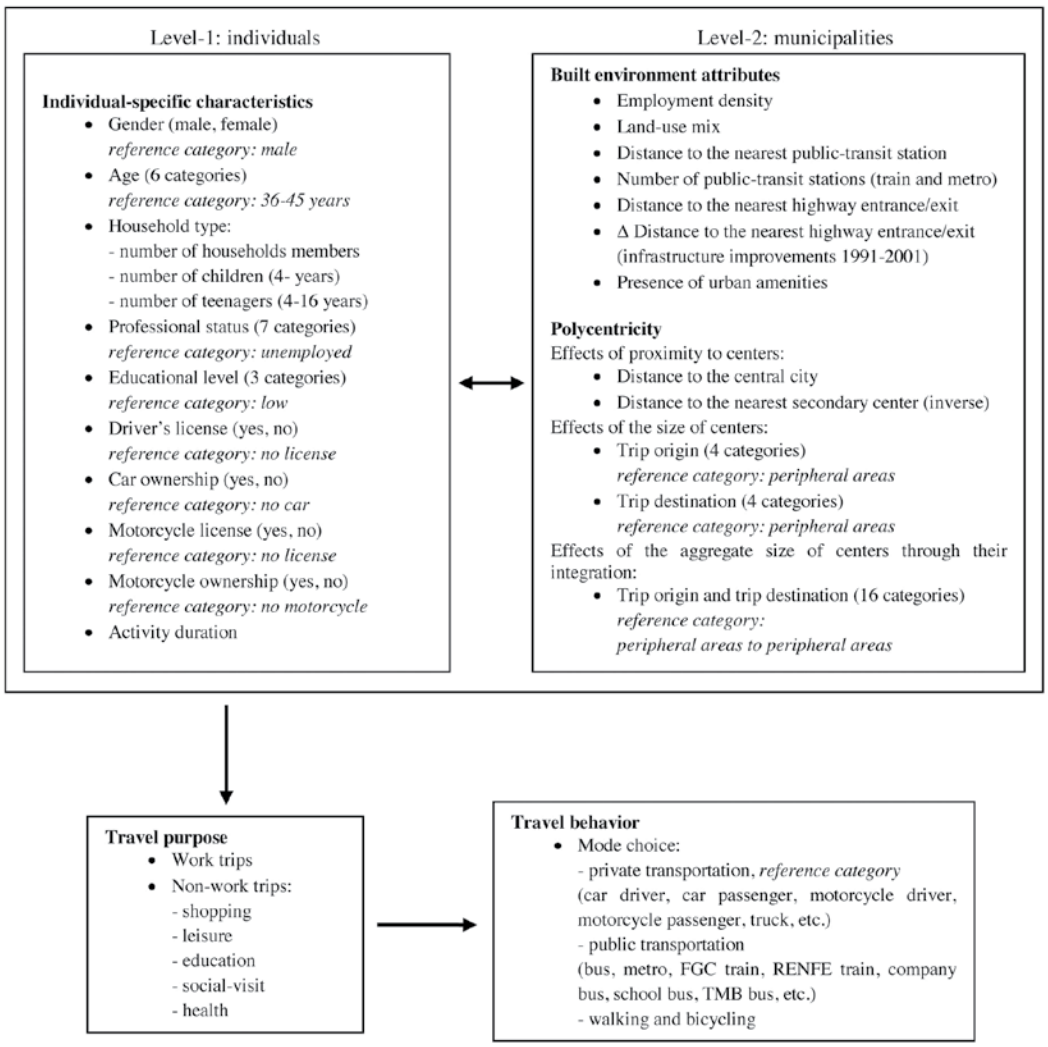


FIGURE 7.3 Research design of the travel mode choice analysis

The built environment attributes are considered by defining most of the locational and morphological attributes noted in section 7.2 on the municipal scale. Those attributes are as follows: employment density, land-use mix, presence of urban amenities, distance to the nearest public-transit (train and metro) station, number of public-transit, distance to the nearest highway entrance/exit, and the increment of the distance to the nearest highway entrance/exit between 1991 and 2001. This variable, the increment of the distance to the nearest highway, represents the effects of infrastructure improvements on travel mode choice. Note that both the infrastructure improvements and the public-transit stations can be observed in Appendix 5.1 to chapter 5.

The data employed to determine these variables come from the following datasets. First, employment data come from the 2001 census data supplied by INE. Second, the land-use dataset is provided by the Department of Territorial Policy and Public Works (hereafter, 'DPTOP') of the Catalan government; that dataset was used in the 2010 Barcelona Metropolitan Territorial Plan. These data define 7 land-use categories: urban-industrial, high-density urban-residential, low-density urban-residential, urban-residential in historical city centers, urban-services, system-urban facilities, and system-urban services. With those data, this study calculates both employment density and land-use diversity, measured using the entropy index proposed by Frank and Pivo (1994). Third, urban-amenities data are also obtained from IDESCAT. These data are measured for the years 2000, 2001, and 2003, depending on the type of amenity (educational, leisure, cultural and sport, health, and social well-being) being considered. To calculate the presence of amenities, a normalized score index ranging from 0 to 100 has been calculated. Fourth, data for highway (entrances and exits) and railway networks relative to the location of the public-transit stations are provided by the DPTOP. The calculation of the distances (in kilometers) to the nearest highway and public-transit station is conducted using Geographic Information System (hereafter, 'GIS') software.

To date, as section 5.2 has noted, most studies centered on the effect of polycentricity on co-location hypothesis and travel mode choice have defined polycentricity in a manner that leaves room for improvement. In this chapter, three different effects of polycentricity are considered in accordance with the conceptual approach to the link between polycentricity on the intra-urban scale and the performance of metropolitan areas proposed in chapter 2 (see Figure 2.2). Each of those effects corresponds to a distinct dimension of a polycentric spatial configuration that plays a role in the development of agglomeration benefits in a metropolitan area. Such an approach to polycentricity could allow this study to define a more comprehensive, systematic empirical framework to examine its effects than other previous research about travel behavior and therefore, to arrive at broader conclusions. Taking the centers (central city and 12 secondary centers) identified in 2001 by the identification method proposed in chapter 5 into account, this research therefore defines the following polycentricity variables to consider three different effects. First, this study considers the attenuation with distance of the agglomeration benefits stemming from the size of centers by defining two variables. These are the distance to the central city (Barcelona) and the inverse of the distance to the nearest secondary center[27]. These two variables have been widely used by scholars to empirically assess the polycentric model in metropolitan areas (see chapter 5) and essentially, they measure the effects of (geographic) proximity to centers (central city and secondary centers).

Second, this research considers the agglomeration benefits stemming from the size of centers by defining two categorical variables. These two variables measure the extent to which the effects of the size of centers differ from (e.g., are more important than) the effects of the size of other types of cities. Whereas the first categorical variable refers to trip origin, the second examines the effects of the size of centers at the trip destination. For each categorical variable, 4 categories are defined: central city

27 Observe that the distance to the nearest secondary center in the inverse form is defined to mitigate the multicollinearity issue arising out of this variable and the distance to the central city. As chapter 5 explained, this decision has been proposed by most of the studies that have assessed the existence of a polycentric model in metropolitan areas (e.g., McMillen and Smith, 2003).

(Barcelona), secondary centers, centers' neighboring areas (municipalities adjacent to centers), and peripheral areas (municipalities located further away from centers). Moreover, these two categorical variables could also proxy for the impact of the built environment attributes, thus adding nuance to their effects. It can be argued that when an individual makes a trip within a center he or she is being influenced by the agglomeration benefits stemming from the size of that center (e.g., a denser environment and accessibility to several types of jobs and amenities) and therefore, one can expect that the effects of the built environment attributes also vary markedly among distinct types of places in a metropolitan area (e.g., centers, neighboring areas of centers, and peripheral areas). The key point is that the presence of (positive) the built environment attributes (and thus, the magnitude of their effects) is dependent on the size of cities because they could indeed be understood as indicators of agglomeration benefits.

Third, this study considers the agglomeration benefits that result from the aggregate size of centers through the strength of their integration by defining a categorical variable that relates distinct trip origins to various trip destinations using the four above-mentioned types of cities. This categorical variable therefore measures the extent to which the effects of the aggregate size of centers through their integration differ from (e.g., are more important than) the effects of the size of other type of cities through their integration. Moreover, this categorical variable enables an examination of the impact of distinct travel patterns (e.g., 'reverse' and 'centralized') proposed by studies such as Cervero and Landis (1992) or Van der Laan (1998) and used by others such as Schwanen et al. (2001, 2003, 2004) and Aguilera et al. (2009). For example, the impact of reverse commuting can be examined by considering the joint effects resulting from the functional links between the central city and other spatial subdivisions (central-city-to-secondary-centers, central-city-to-centers'-neighboring-areas, and central-city-to-peripheral-areas). The only data required to calculate these variables come from the matrix of minimum road distances (in kilometers) between municipalities in Catalonia provided by DPTOP for 2001. From those data, the distance from each Barcelona metropolitan region's municipality to the central city and to the nearest secondary center is calculated using GIS software.

Methods

Descriptive statistics: location and dynamics of travelers

Descriptive statistics are utilized to reveal whether the co-location hypothesis is corroborated for work and non-work trips. To do so, this study first considers the four spatial subdivisions noted in the previous sub-section (central city, secondary centers, centers' neighboring areas, and peripheral areas), and second develops a set of travel indicators for characterizing the location and dynamics of people traveling to and from centers (central city and secondary centers). With this spatial division for the Barcelona metropolitan region, this research can distinguish the patterns of trips to and from centers' neighboring areas from patterns related to peripheral areas. The travel dynamics of those 'suburban' travelers who are more closely related to centers (i.e., residents of municipalities near centers) therefore can be better approximated.

The travel indicators are designed to capture four trends. First, the indicators are designed to capture trends related to which trip origin/trip destination pairing appears to be the most important relative to the total trips generated in the metropolitan area. Second, the indicators are designed to capture trends related to the extent to which people traveling from a center are traveling to the same center, close to that center, or to another center. Third, the indicators are designed to capture trends related to the extent to which trips to a center are made by that center's residents versus nonresidents (either from neighboring cities or other centers). Fourth, the indicators are designed to capture trends related to the average trip distance and average trip time of residents of centers compared to residents of centers' neighboring areas, peripheral areas, and the overall metropolitan region. Moreover, this study relates the analysis of travelers' locations and dynamics not only to the changes in Barcelona's polycentric metropolitan structure (by examining the trends in each spatial subdivision's jobs and population) but also to the various types of centers. As section 7.3 has noted, studies in the literature have distinguished centers based on their locations relative to the central city, assuming decentralization is the only pathway to polycentricity. In this analysis, centers are distinguished according to their origin of formation (decentralization and incorporation-fusion) based on the identification method proposed in chapter 5. In this regard, important nuances will can be drawn from the analysis of how centers that result from incorporation-fusion are denoted as 'large', 'high-order', or 'mature' according to the identification method of chapter 5 affect the co-location of people, jobs and urban amenities compared to those centers that result from decentralization and are denoted as 'emerging' or 'low-order'.

Empirical model framework: multilevel multinomial logit model

Multilevel multinomial logit models are used to examine which factors affect travel mode choice for both work and non-work trips. Multinomial logit models are a statistical technique used in many disciplines (e.g., political science, sociology, etc.); they are the most theoretically developed in econometrics under the label of discrete-choice models (McFadden 1973; Train, 2003) to examine individuals' choices among a set of alternatives. It can be understood as an extension of a logistic regression that allows each alternative of a response variable to be compared to a reference alternative, providing a number of logistic models.

In transportation research, scholars have commonly used multinomial logit models with three alternatives (or less commonly, four). More specifically, scholars have aimed to examine the impact of individual attributes, built environment attributes and polycentricity on an individual's likelihood of choosing between driving a car (or private transportation), taking public transportation and bicycling-walking (see Bento et al., 2005; Dieleman et al., 2002; Schwanen et al., 2001; Song et al., 2012; Susilo and Maat, 2007). However, these studies have used individuals as a basic unit of analysis, linking other variables at various geographical levels to that first-level individual data without disentangling the within-grouping effects (between individuals) and the between-grouping effects (across locations). Although these studies do not suffer from the risk of ecological fallacy like studies that have used aggregate data (e.g., García-Palomares, 2010), their treatment of the microlevel variation derived from using hierarchical data and estimating standard (multinomial) logit models can result in misleading results, as noted in section 7.3.

To address this issue, the econometric literature (e.g., Raudenbush and Byrk, 2002; Snijders and Bosker, 2012) has proposed the use of multilevel modeling. A multilevel model manages data clusters at different levels by extending the random part of a model. Consequently, multilevel models are based on both a fixed and a random part. Whereas the fixed part represents the relationship between the response variable and the explanatory variables, the random part enables variation around the intercept and/or the fixed part of the model (coefficient/s of the variables). Multilevel modeling has also been widely employed in travel research, for example, with respect to the determinants of travel-time ratio and daily distance traveled (e.g., Schwanen and Dijst, 2002). Nevertheless, only Schwanen et al. (2004) apply such models to examine the link between polycentricity, the built environment, and travel mode choice. More specifically, Schwanen et al. (2004) estimate a multilevel logit model with a binary response variable (working commuting as a car driver or not) by nesting individuals within households, municipalities, and daily urban systems.

In this chapter, this binary multilevel logit model cannot be replicated because this research compares more than one dichotomy. To specify the multilevel version of a multinomial logit model, this study follows Skrondal and Rabe-Hesketh (2003), who define a multilevel multinomial logit model as a mixed generalized linear model with linear predictors (equation 7.1) and a multinomial logit link (equation 7.2) in this manner:

$$\eta_{ij}^{(m)} = \alpha^{(m)} + \boldsymbol{\beta}_1^{(m)\prime}\boldsymbol{X}_{1ij} + \boldsymbol{\beta}_2^{(m)\prime}\boldsymbol{X}_{2j} + u_{ij}^{(m)} + u_j^{(m)}$$

EQUATION 7.1

$$P\left(Y_{ij} = m \mid \boldsymbol{X}_{1ij}, \boldsymbol{X}_{2j}, \boldsymbol{u}_{ij}, \boldsymbol{u}_j\right) = \frac{\exp\{\eta_{ij}^{(m)}\}}{1+\sum_{k=2}^{M}\exp\{\eta_{ij}^{(k)}\}}$$

EQUATION 7.2

where, as previously, m = 1, 2, ..., M denotes the response category (individuals' travel mode choices); j = 1, 2,..., J denotes the cluster (municipalities), and i = 1, 2,..., n_j denotes the subject (individuals) at level-1 of the (j^{th}) cluster at a higher geographical scale (level-2). The response (dependent) variable Y_{ij} has (conditional on the random effects) a multinomial distribution, taking values in the set of alternatives (1, 2, ..., M), where m = 1 is the reference category or outcome (private means of transport) for which all of the parameters and the random errors are set to 0. Thus, similar to standard multinomial logit models (see, e.g., Train, 2003), the conditional probability of Y_{ij} = 1 is $1/\left(1+\sum_{k=2}^{M}\exp\left\{\eta_{ij}^{(k)}\right\}\right)$. Each equation has specific explanatory variables and parameters. Whereas ($\mathbf{X}_{1ij}$) represents the vector attributes of individual (i) nested within municipality (j) with the corresponding fixed coefficients denoted by ($\boldsymbol{\beta}_1$), ($\mathbf{X}_{2j}$) stands for the vector attributes at the cluster-level (municipality), with the corresponding fixed coefficients denoted by ($\boldsymbol{\beta}_2$). The explanatory variables at the subject ($\mathbf{X}_{1ij}$) and cluster ($\mathbf{X}_{2j}$) level used in this analysis are the individual-specific characteristics, the built environment attributes, and the polycentricity variables presented in Figure 7.3. Finally, ($\mathbf{u}_j$) is the random intercept at level-2 (municipalities), where it is assumed that it has a normal distribution with mean 0. This random intercept, which represents the model's random effects, is shared by all of the units in the same cluster (j) and thus, can be interpreted as a cluster-level unobserved heterogeneity. Moreover, this study constrains the random effects ($\sigma^2 u_j$, variance at cluster-level) to be equal for choosing m = 2 (public transportation) and m = 3 (walking-bicycling)[28] and constrains their variance terms at the lowest level ($\sigma^2 u_{ij}$) to 1, following what Snijders and Bosker (2012) have stated about multilevel models with a categorical dependent variable.

Note that this multilevel model can be extended by including random coefficients, allowing the effects of certain explanatory variables to vary among level-2 units—for example, by allowing the impact of gender on mode choice (represented by the slope of its corresponding β coefficient) to vary among municipalities. However, multilevel multinomial logit models with random slope and intercept effects lead to more complicated multilevel models, which sometimes are either difficult to estimate or have no statistically significant results. Moreover, this study's interest focuses on examining the effects of distinct polycentricity variables measured at the cluster-level. Consequently, this study restricts itself to estimating multilevel multinomial logit models with shared random-intercept effects.

To fit the multilevel multinomial logit models, this study uses maximum likelihood estimation following the procedure of Rabe-Hesketh et al. (2002, 2005). This implies that adaptive Gaussian quadrature was

28 Another option would have been to consider separate but correlated effects. This would imply obtaining two different estimated variances at the cluster-level—one for selecting public transportation (m = 2) and another for selecting bicycling-walking (m = 3)—and an estimated covariance. The correlation between the two random effects is obtained from the covariance and the two estimated variances (covariance / √ [variance (m = 2) + variance (m = 3)]).

used to evaluate and maximize the marginal log-likelihood calculations for fitting the models instead of alternative numerical integration methods such as Gaussian quadrature, marginal quasi-likelihood, penalized quasi-likelihood, or Markov Chain Monte Carlo. The use of adaptive Gaussian quadrature over these other integration approaches when dichotomous responses are involved (as in this research) entails a promising improvement estimation, as proven by Rabe-Hesketh et al. (2002). In this chapter's application of adaptive Gaussian quadrature integration, 8 quadrature points appear sufficient for an accurate estimate. The estimation process of multilevel multinomial logit models is therefore operationalized as follows.

First, this study considers multilevel multinomial logit models not only for both work and non-work trips but also for each individual non-work trip purpose (see Figure 7.3) to be estimated. Second, before adding explanatory variables, an intercept-only model—i.e., a model including random terms but not independent variables—is estimated. When the estimates for the random terms in this model are statistically significantly larger than zero, the multilevel specification is correct and the expectation that individuals clustered in the same municipality will share locational effects is corroborated. The estimates of all of the multilevel multinomial logit models have confirmed this expectation[29]. Third, individual-specific characteristics (ISC) are added to this intercept-only model. This random intercept model defines the baseline model (model 0: ISC) for which the model fit improvement relative to the intercept-only model is confirmed using a likelihood-ratio test that considers both models[30]. Fourth, this work defines four different model specifications by including built environment attributes (model 1: ISC-BE) and polycentricity variables related to the effects of proximity to centers (model 2: ISC-P1), the effects of the size of centers (model 3: ISC-P2), and the effects of the aggregate size of centers through their integration (model 4: ISC-P3). Again, likelihood-ratio tests are used to corroborate the model fit improvements.

§ 7.5 Polycentricity and the co-location hypothesis

Table 7.1 presents the shares of the work and non-work trips generated between the central city, secondary centers, centers' neighboring areas, and peripheral areas relative to the overall metropolitan region. In 2001, the Barcelona metropolitan region had a polycentric structure in the sense that the central city and secondary centers retained and attracted a large share of the travelers. This percentage amounts to 68.33% of all work trips and 51.01% of all non-work-related trips. However, the close examination of mobility patterns since 1991 allows me to distinguish between two different trends. First, work-related travel has been characterized by a decrease in the proportion of residents (-5.42%) and non-residents (-0.95%, which results from the sum of [-1.19% - 0.42% + 0.66%]) of the central city who work in the central city, which implies that the proportion of trips not involving the central city increased moderately. This moderate increase has primarily focused on trips between centers' neighboring areas and secondary centers (+1.03%), between centers' neighboring areas (+1.34%), and between peripheral areas (+1.18%). Second, and in contrast, non-work trips' trends have revealed that

29 For example, the estimated variance for the work-trips model is 0.801 with a standard error of 0.052, whereas the estimated variance for the non-work-trips model is 0.345, with a standard error of 0.058. That means that the correspondent t-values are 15.40 (0.801/0.052) and 5.94 (0.345/0.058), respectively.

30 With this test, one can corroborate whether the diminished log-likelihood between two models, which leads to a better model fit, is statistically significant. This study finds that the log-likelihood differences (e.g., 4,425.90 for the work-trip model and 9,915.90 for the non-work-trips model) have a significance of more than 99% for all considered trip purposes, thus confirming all of the model fit improvements.

the central city of Barcelona has become increasingly important as a destination for its own residents to perform daily activities (+11.12%). Moreover, there has been an increase in the proportion of trips between secondary centers (+1.82%) and trips between centers' neighboring areas (+1.55%). However, non-work trips originating and remaining in areas located further away from centers ('peripheral areas') decreased (-2.87%). These travel pattern trends could therefore be interpreted as evidence that since 1991, the total number of non-work trips, more than travel for work, has become more oriented towards centers (central city and secondary centers) and their neighboring municipalities.

PLACE OF TRIP ORIGIN	PLACE OF TRIP DESTINATION	WORK TRIPS				NON-WORK TRIPS		
		1991	1996	2001	PERCENTAGE DIFFERENCE (1991-2001)	1996	2001	PERCENTAGE DIFFERENCE (1996-2001)
Central city (Barcelona)	Central city (Barcelona)	33.38%	28.05%	27.96%	-5.42%	12.51%	23.63%	11.12%
Central city (Barcelona)	Secondary centers	2.94%	3.51%	2.95%	0.00%	2.96%	2.85%	-0.11%
Central city (Barcelona)	Centers' neighboring areas	2.51%	2.79%	2.23%	-0.28%	3.58%	3.21%	-0.37%
Central city (Barcelona)	Peripheral areas	0.72%	0.84%	0.77%	0.06%	2.76%	2.18%	-0.58%
Secondary centers	Central city (Barcelona)	7.37%	7.05%	6.17%	-1.19%	3.01%	2.02%	-0.98%
Secondary centers	Secondary centers	17.98%	17.47%	18.10%	0.12%	14.19%	16.00%	1.82%
Secondary centers	Centers' neighboring areas	3.49%	4.15%	4.01%	0.52%	4.14%	3.22%	-0.92%
Secondary centers	Peripheral areas	0.73%	1.02%	1.18%	0.45%	2.24%	1.63%	-0.61%
Centers' neighboring areas	Central city (Barcelona)	5.00%	5.13%	4.59%	-0.42%	3.64%	1.85%	-1.80%
Centers' neighboring areas	Secondary centers	3.01%	3.93%	4.04%	1.03%	4.15%	2.40%	-1.75%
Centers' neighboring areas	Centers' neighboring areas	8.84%	9.36%	10.18%	1.34%	13.54%	15.08%	1.55%
Centers' neighboring areas	Peripheral areas	1.06%	1.37%	1.44%	0.38%	2.58%	1.87%	-0.71%
Peripheral areas	Central city (Barcelona)	2.05%	2.81%	2.71%	0.66%	2.77%	1.27%	-1.49%
Peripheral areas	Secondary centers	1.05%	1.58%	1.81%	0.76%	2.26%	0.99%	-1.27%
Peripheral areas	Centers' neighboring areas	1.42%	1.98%	2.22%	0.80%	2.59%	1.57%	-1.02%
Peripheral areas	Peripheral areas	8.45%	8.96%	9.63%	1.18%	23.09%	20.21%	-2.87%

TABLE 7.1 Percentage of work and non-work trips among the central city, secondary centers, centers' neighboring areas and peripheral areas since 1991

Note(s): work travel aggregate data come from the 1991, 1996 and 2001 census provided by IDESCAT (Institut d'Estadística de Catalunya), whereas non-work travel data come from the 1996 and 2001 EMQ (Daily Mobility Survey) supplied by ATM (Autoritat del Transport Metropolità). The EMQ data also provides information about work trips. These results are available on request.

It is also important to note that in 2001, more than half of people living in a secondary center performed their daily activities in the same center (Table 7.2). This proportion is quite similar in the two types of centers considered. Whereas large centers—i.e., 'incorporated-fused' centers—keep 65.21% (+11.00% since 1996) of the non-work trips within their boundaries, emerging centers—i.e., 'decentralized' centers—keep 61.95% (+7.74% since 1996) of their population for non-work trip purposes. In addition, the number of people traveling from a center to its neighboring areas (approximately 12.76% to 14.55%) or to the central city (approximately 8.24% to 10.46%) is greater than the number of people traveling to peripheral areas (approximately 7%). This could indicate that centers depend less on urban functions located in peripheral areas than those amenities located in their neighboring areas or in the central city when their urban functions do not fulfill the demands of their residents. There is, however, less evidence for a center retaining its population for work trips in 2001. Although approximately half of workers living in a large center work in this same center (53.99%), that proportion is less than half (44.66%) for an emerging center. Moreover, approximately 19.62% (large centers) to 25.63% (emerging centers) of the population living in a center held a job in the central city in 2001, although residents of centers became less dependent on jobs located in Barcelona (-4.47% and -2.68%) and more oriented toward jobs offered by other (secondary) centers (+3.50% and +2.57%).

	PLACE OF RESIDENCE	1991		1996		2001		PERCENTAGE DIFFERENCE (SINCE INITIAL YEAR)	
		LARGE CENTER	EMERGING CENTER	LARGE CENTER	EMERGING CENTER	LARGE CENTER	EMERGING CENTER	LARGE CENTER	EMERGING CENTER
PLACE OF DESTINATION	Work trips								
	Central city (Barcelona)	24.09%	28.31%	22.64%	28.03%	19.62%	25.63%	-4.47%	-2.68%
	Same (secondary) center	56.29%	47.99%	51.70%	43.48%	53.99%	44.66%	-2.29%	-3.33%
	Other (secondary) center	5.68%	8.10%	8.40%	10.49%	9.18%	10.67%	3.50%	2.57%
	Centers' neighboring areas	11.44%	13.29%	13.81%	14.65%	13.27%	14.84%	1.83%	1.55%
	Peripheral areas	2.51%	2.30%	3.45%	3.34%	3.93%	4.19%	1.42%	1.89%
	Total	100%	100%	100%	100%	100%	100%		
	Non-work trips								
	Central city (Barcelona)			11.23%	17.66%	8.24%	10.46%	-2.99%	-0.77%
	Same (secondary) center			54.21%	44.75%	65.21%	61.95%	11.00%	7.74%
	Other (secondary) center			7.52%	10.47%	4.86%	7.71%	-2.66%	0.19%
	Centers' neighboring areas			17.25%	18.49%	14.55%	12.76%	-2.70%	-4.49%
	Peripheral areas			9.78%	8.63%	7.14%	7.12%	-2.64%	-2.66%
	Total			100%	100%	100%	100%		

TABLE 7.2 Destinations of people traveling from a secondary center for work and non-work trips since 1991 (percentages)

Note(s): work travel aggregate data come from the 1991, 1996 and 2001 census provided by IDESCAT (Institut d'Estadística de Catalunya), whereas non-work travel data come from the 1996 and 2001 EMQ (Daily Mobility Survey) supplied by ATM (Autoritat del Transport Metropolità).

	PLACE OF DESTINATION	1991		1996		2001		PERCENTAGE DIFFERENCE (SINCE INITIAL YEAR)	
		LARGE CENTER	EMERGING CENTER	LARGE CENTER	EMERGING CENTER	LARGE CENTER	EMERGING CENTER	LARGE CENTER	EMERGING CENTER
PLACE OF RESIDENCE	Work trips								
	Central city (Barcelona)	10.78%	15.49%	11.67%	18.03%	9.19%	15.88%	-1.59%	0.39%
	Same (secondary) center	68.14%	51.99%	61.16%	40.57%	62.67%	40.77%	-5.47%	-11.22%
	Other (secondary) center	5.91%	12.33%	7.80%	16.27%	8.27%	16.36%	2.36%	4.04%
	Centers' neighboring areas	11.22%	15.00%	13.71%	18.21%	13.71%	18.65%	2.49%	3.65%
	Peripheral areas	3.95%	5.20%	5.67%	6.92%	6.16%	8.33%	2.22%	3.13%
	Total	100%	100%	100%	100%	100%	100%		
	Non-work trips								
	Central city (Barcelona)			11.05%	17.49%	12.36%	14.12%	1.31%	3.07%
	Same (secondary) center			54.31%	44.63%	66.07%	66.38%	11.77%	12.07%
	Other (secondary) center			7.53%	10.45%	5.48%	6.69%	-2.05%	-0.84%
	Centers' neighboring areas			17.30%	18.57%	11.31%	9.31%	-5.99%	-7.99%
	Peripheral areas			9.81%	8.85%	4.77%	3.50%	-5.03%	-6.31%
	Total			100%	100%	100%	100%		

TABLE 7.3 Place of residence of people traveling to a secondary center for work and non-work trips since 1991 (percentages)

Note(s): work travel aggregate data come from the 1991, 1996 and 2001 census provided by IDESCAT (Institut d'Estadística de Catalunya), whereas non-work travel data come from the 1996 and 2001 EMQ (Daily Mobility Survey) supplied by ATM (Autoritat del Transport Metropolità).

The analysis of the place of residence of people traveling to a center in 2001 (Table 7.3) shows that most of the jobs located in a large center are filled by the center's own residents (62.67%); in contrast, in an emerging center the percentage is less than half (40.77%). This meant a significant reduction in the proportion of jobs located in centers filled by that center's own residents since 1991 (-5.47% and -11.22%), which could be better explained by their greater attractiveness to residents from elsewhere than because people living in these centers began to work elsewhere (e.g., compare the result of summing the percentage difference since 1991 regarding emerging centers shown in Table 7.3 [0.39% + 4.04% + 3.65% + 3.13% = 11.21%] with the result of summing the corresponding figures presented in Table 7.2 [-2.68% + 2.57% + 1.55% + 1.89% = 3.33%]). More specifically, other jobs in a large center are primarily filled by people living in neighboring areas (13.71%) and in the central city (9.19%), whereas other jobs in an emerging center are filled by residents of centers' neighboring areas (18.65%) and of other (secondary) centers (16.36%). However, the proportion of a center's residents who do not travel elsewhere for non-work trips has increased considerably since 1991. Whereas 66.07% (+11.77%) of non-work-related trips toward a large center originated in the same center in 2001, 66.38% (+12.07%) of trips with a destination to an emerging center were generated in that same center. Furthermore, the second-most important share of travelers to centers (large and emerging) comes from their neighboring areas (11.31% and 9.31%) and the central city (12.36% and 14.12%). Consequently, it can be observed that more than 75% of non-work trips towards centers in 2001 originated either in or close (adjacent municipalities) to them.

These observations are also supported by the results reached by the analysis of the average trip distance and time (Table 7.4). People living either in the central city or in secondary centers had a shorter average trip distance (2.93 and 6.83 km) and average trip time (3.52 and 8.38 minutes) for work trip purposes in 2011[31] than those people whose place of residence was in peripheral areas (11.94 km and 11.82 minutes). Additionally, on average, they experienced lower travel costs than in the overall metropolitan region (10.87 km and 11.27 minutes). Non-work travel also exhibits a similar trend. Whereas residents of the central city and secondary centers spend an average of 3.29 and 4.84 km, which is translated into 3.82 and 6.18 minutes, respectively, residents of peripheral areas (8.65 km and 8.75 minutes) or the overall metropolitan region (7.65 km and 8.11 minutes) experience longer trip distances and times.

Moreover, it seems that residents of centers' neighboring areas benefit more from their proximity to centers. Both for work and non-work trips, they have a shorter average trip distance (9.79 and 6.34 km) and time (11.00 and 7.34 minutes) than the aforementioned average trip lengths and durations for residents of either peripheral areas or the overall metropolitan region. Building on this observation and considering the average trip distance and time in relation to the place of origin and destination (results not reported but available upon request), it is possible to highlight, for example, the following travel trend that also points to the importance of the effects of proximity to centers. The 11.31% and 9.31% of non-work trips originating in centers' neighboring areas and traveling toward centers (Table 7.3) implied a shorter average trip distance and time in 2011 (8.99 km and 12.62 minutes) than if the trip destination was the central city (15.33 km and 18.73 minutes) or peripheral areas (12.35 km and 13.34 minutes). Note also that on average, people living in large centers experience a shorter trip distance and time for work and non-work trips than people living in emerging centers. This confirms the assumption that centers arising out of incorporation-fusion instead of decentralization have a greater ability to minimize their residents' trip distances and times.

In terms of the growth of average trip distance and time since 1991, the following can be observed. Whereas the average trip distance in the Barcelona metropolitan region has increased for work trips (+7.47%) and decreased for non-work trips (-12.58%) since 1991, the average trip time has decreased for both work and non-work trips (-5.82% and -6.47%). In addition, residents of secondary centers (particularly large centers) and to a lesser extent, residents of the central city and of centers' neighboring areas, experience shortened trip distances and trip times. For example, on average, residents of large centers have reduced their travel time for work and non-work travel by -12.49% and -13.71% since 2001, respectively, whereas people living in peripheral areas have experienced a reduction of only -4.82% and -4.94%, respectively.

31 These 2011 results are calculated by using the matrices of distance and time provided by the DPTOP of the Catalan government for 2011 and by holding the matrix of flows constant since 2001 because of the limitations of the 2011 census data mentioned in section 7.4.

INDIVIDUAL CENTERS AND SPATIAL SUBDIVISIONS	AVERAGE TRIP DISTANCE (KILOMETERS)					AVERAGE TRIP TIME (MINUTES)		
	1991	1996	2001	2011[A]	TREND SINCE INITIAL YEAR	2001	2011[A]	TREND SINCE INITIAL YEAR
Work trips								
Badalona	6.34	7.81	7.67	6.56	3.38%	8.96	8.82	-1.60%
Barcelona	3.27	3.76	2.87	2.93	-10.33%	3.69	3.52	-4.55%
Cornellà de Llobregat	9.28	8.82	7.68	8.06	-13.09%	10.72	10.90	1.74%
Granollers	4.68	6.38	6.30	6.03	28.85%	7.50	6.73	-10.27%
Hospitalet de Llobregat (L')	7.45	7.48	6.24	6.49	-12.82%	13.35	9.86	-26.15%
Martorell	8.06	8.33	7.47	7.80	-3.32%	7.36	8.81	19.66%
Mataró	3.50	5.04	5.37	5.18	48.10%	4.82	4.87	1.06%
Prat de Llobregat (El)	4.84	6.34	6.82	6.43	32.85%	8.68	8.69	0.02%
Rubí	7.36	7.77	7.33	6.09	-17.24%	8.65	7.57	-12.48%
Sabadell	4.96	5.22	4.84	4.80	-3.21%	7.56	6.55	-13.36%
Sant Cugat del Vallès	12.48	11.40	8.31	9.54	-23.55%	13.08	11.53	-11.91%
Terrassa	6.20	6.09	4.68	5.29	-14.69%	7.31	6.49	-11.22%
Vilanova I la Geltrú	5.35	8.18	9.74	9.73	82.00%	8.29	9.70	17.05%
Central city (Barcelona)	3.27	3.76	2.87	2.93	-10.33%	3.69	3.52	-4.55%
Secondary (all) centers	6.71	7.40	6.87	6.83	1.87%	8.86	8.38	-5.43%
Secondary (large) centers	5.78	6.54	6.06	5.78	-0.11%	8.31	7.27	-12.49%
Secondary (emerging) centers	8.00	8.61	8.00	8.31	3.88%	9.63	9.93	3.10%
Centers' neighboring areas	9.69	10.90	9.82	9.79	1.13%	11.97	11.00	-8.08%
Peripheral areas	10.79	12.76	11.97	11.94	10.64%	12.42	11.82	-4.82%
Overall metropolitan region	10.11	11.83	10.90	10.87	7.47%	11.97	11.27	-5.82%
Non-work trips								
Badalona		3.67	4.01	3.43	-6.30%	5.05	4.76	-5.80%
Barcelona		5.92	3.26	3.29	-44.48%	3.97	3.82	-3.76%
Cornellà de Llobregat		4.70	6.52	6.93	47.35%	9.96	9.96	0.07%
Granollers		6.11	5.70	5.42	-11.33%	7.38	6.52	-11.62%
Hospitalet de Llobregat (L')		6.01	4.41	4.66	-22.39%	10.40	7.63	-26.62%
Martorell		12.08	4.58	4.72	-60.88%	4.47	5.31	18.79%
Mataró		4.26	3.48	3.39	-20.52%	3.21	3.15	-1.80%
Prat de Llobregat (El)		4.54	4.41	4.20	-7.57%	5.92	5.92	-0.11%
Rubí		3.68	6.32	5.27	43.40%	7.57	6.69	-11.66%
Sabadell		5.15	4.72	4.75	-7.74%	7.65	6.65	-12.98%
Sant Cugat del Vallès		5.74	4.85	5.05	-12.00%	7.13	6.26	-12.27%
Terrassa		5.66	4.61	5.14	-9.30%	7.07	6.30	-10.99%
Vilanova I la Geltrú		5.09	5.23	5.12	0.46%	4.31	4.99	15.81%
Central city (Barcelona)		5.92	3.26	3.29	-44.48%	3.97	3.82	-3.76%
Secondary (all) centers		5.56	4.90	4.84	-12.90%	6.68	6.18	-7.47%
Secondary (large) centers		4.93	4.75	4.58	-7.16%	6.90	5.96	-13.71%
Secondary (emerging) centers		6.43	5.12	5.20	-19.07%	6.36	6.49	2.03%
Centers' neighboring areas		7.63	6.46	6.34	-17.01%	8.15	7.34	-9.88%
Peripheral areas		9.69	8.74	8.65	-10.78%	9.20	8.75	-4.94%
Overall metropolitan region		8.75	7.74	7.65	-12.58%	8.67	8.11	-6.47%

TABLE 7.4 Evolution of average trip distance and time relative to place of residence for work and non-work travel since 1991

a. These results are calculated using the matrices of distance and time provided by the DPTOP of the Catalan government for 2011 and by holding the matrix of flows constant since 2001 because of the aforementioned limitations of the 2011 census data.
Note(s): work travel aggregate data come from the 1991, 1996 and 2001 census provided by IDESCAT (Institut d'Estadística de Catalunya), whereas non-work travel data come from the 1996 and 2001 EMQ (Daily Mobility Survey) supplied by ATM (Autoritat del Transport Metropolità).

In summary, since 1991, two distinct trip patterns can be observed. First, most of the centers' residents perform their daily activities either in or close to those centers. Second, most of the jobs and urban functions in centers are filled and used either by their own residents or by people living close by. These travel patterns translate into shorter average trip distances and trip times for residents of centers (central city and secondary centers) and their neighboring municipalities. Additionally, the average trip distance and trip time of the overall metropolitan region have been reduced over time with regard to non-work travel, whereas the average trip distance of people living in the Barcelona metropolitan region has slightly increased due to the substantial increase in trip distance among the residents of areas located further away from centers (i.e., peripheral areas). These findings all point to the development of centers that contribute to co-location, not more sprawl. In other words, Barcelona's polycentric development has enabled the co-location of people, jobs, and urban amenities, leading to shorter trip lengths and durations.

In this regard, it is also important to note that changes in the metropolitan spatial structure of the Barcelona metropolitan region since 1991 could also have also influenced the proximity of economic functions, daily activity functions and residential functions. More specifically, the increase in the number of secondary centers from 8 in 1991 to 12 in 2001, as chapter 5 has shown, could have facilitated people's increasing optimization of their work and non-work travel by allowing them to choose from multiple locations with a strong presence of both jobs and urban functions. Indeed, Table 7.5 reveals that during the 1991-2001 period, secondary centers had a greater concentration of jobs in both absolute (+169,987) and relative (+54,32%) terms; they also had a greater concentration of population in absolute terms (+242,807) than the central city, centers' neighboring areas, and peripheral areas. These numbers are even higher if we extend the period of analysis to 2011. The next section presents the results on the relation between polycentricity and travel mode choice.

SPATIAL SUBDIVISIONS	1991	2001	ABSOLUTE DIFFERENCE (1991-2001)	PERCENTAGE DIFFERENCE (1991-2001)	2011[A]	ABSOLUTE DIFFERENCE (1991-2011)	PERCENTAGE DIFFERENCE (1991-2011)
Central city (Barcelona)							
Jobs	746,249	743,594	-2,655	-0.36%	811,578	65,329	8.75%
Population	1,643,542	1,505,325	-138,217	-8.41%	1,611,013	-32,529	-1.98%
Secondary centers							
Jobs	312,918	482,885	169,967	54.32%	502,968	190,050	60.73%
Population	1,065,835	1,308,642	242,807	22.78%	1,482,525	416,690	39.10%
Centers' neighboring areas							
Jobs	331,689	334,611	2,922	0.88%	342,652	10,963	3.31%
Population	1,009,003	870,471	-138,532	-13.73%	1,027,151	18,148	1.80%
Peripheral areas							
Jobs	170,462	233,696	63,234	37.10%	242,815	72,353	42.45%
Population	546,042	705,975	159,933	29.29%	902,474	356,432	65.28%

TABLE 7.5 Number of jobs and inhabitants in each spatial subdivision since 1991

a. The number of jobs is calculated accorded to the 2011 census data.
Note(s): employment and population data come from the 1991, 2001, and 2011 census provided by IDESCAT (Institut d'Estadística de Catalunya).

§ 7.6 Polycentricity and travel mode choice

The results from the multilevel multinomial logit models for work and non-work trips are shown in Tables 7.6 and 7.7, respectively. In each of the models, private of transportation is considered as the reference category. This means that the coefficients (β) and the average marginal effects (hereafter, 'AMEs') given in Tables 7.6 and 7.7 express the use of public transportation and bicycling-walking relative to the use of private transportation. For instance, in the first model's (model 1:ISC-BE) explanation of the relative use of public transportation (Table 7.6), the coefficient -1.983*** for owning a car indicates that the relative use of public transportation for work-related travel decreases strongly if an individual owns a car and, conversely, increases if an individual does not own a car. AMEs allow both a clearer interpretation of this coefficient and a quantification of its effects on travel mode choice. Additionally, AMEs provide policymakers with information that is useful when creating planning-policy recommendations (see, e.g., Ewing and Cervero, 2010) and thus, their estimation could shed more light on how the benefits of polycentricity can be realized in planning practice. An AME of -0.1781 for owning a car indicates that the relative probability of using public transportation instead of private transportation decreases by 17.81% for an individual who owns a car (and increases by 17.81% if the individual does not own a car). There are also categorical variables in the multilevel multinomial logit models (e.g., educational level). In these cases, the coefficients (β) and AME of the other categories are expressed relative to the reference category of each categorical variable and are influenced by the other explanatory variables included in the model. For instance, the coefficient 0.324*** for highly educated individuals on the variable of educational level in the first model shown in Table 7.6 shows that highly educated individuals are more likely to use public transportation than private transportation for work trips compared to less-educated individuals (the reference category).

The effects of individual-specific characteristics

Most of the trip makers' sociodemographic attributes are statistically significant predictors for work-related trips (Table 7.6) across all of the model specifications (models 1 to 4), and they reinforce the findings obtained by previous studies on mode choice. In particular, having a high educational level relative to a low educational level, not having a driver's license, not owning a car, not owning a motorcycle, being older than 56 years of age relative to being between 36-45 years of age, and being a female increases the propensity to take public transportation or to use slow travel modes such as bicycling-walking instead of private transportation. Moreover, not having a motorcycle license, spending more time at the activity (for which the trip is made), and being part of a family either without or with a small number of children or teenagers are significant determinants of choosing public transportation instead of private transportation to travel to work. These results are consistent with other previous studies that have also found similar influences with respect to age (e.g., Commins and Nolan, 2011; Schwanen et al., 2001, 2004), gender (e.g., Bento et al., 2005; Cervero, 2002; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008), household type (e.g., Commins and Nolan, 2011; Dieleman et al., 2002; Schwanen et al., 2001), ownership of private transportation or having a driver's license (e.g., Cervero, 1996a; Cervero and Kockelman, 1997; Schwanen et al., 2001, 2004; Song et al., 2012), and education (e.g., Schwanen et al., 2001; Susilo and Maat, 2007). However, individuals' professional status does not seem to be an important predictor of travel mode choice for work trips. Status is only a significant predictor of travel mode choice for 'business owners' who are more likely to take private transportation instead of public transportation.

RANDOM INTERCEPT MODELS DETERMINANTS OF TRAVEL MODE CHOICE: WORK-TRIP PURPOSES	ALTERNATIVE CATEGORY (2) = PUBLIC TRANSPORTATION							
	MODEL 1: ISC-BE		MODEL 2: ISC-P1		MODEL 3: ISC-P2		MODEL 4: ISC-P3	
	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME
Fixed part								
Level 1 Individual-specific characteristics								
Gender (reference = male)	0.536***	0.0425***	0.526***	0.0444***	0.483***	0.0354***	0.499***	0.0399***
Age cohorts								
36-45 years (reference)								
16-25 years	-0.372***	-0.0334***	-0.388***	-0.0372***	-0.354***	-0.0311***	-0.330***	-0.0273***
26-35 years	-0.235***	-0.0222**	-0.260***	-0.0274***	-0.220***	-0.0206**	-0.205**	-0.0196**
46-55 years	0.099	0.0061	0.096	0.0064	0.088	0.0048	0.106	0.0075
56-65 years	0.206*	0.0070	0.214*	0.0079	0.198	0.0065	0.203	0.0089
65+ years	0.719**	0.0246	0.738**	0.0245	0.622*	0.0148	0.668**	0.0211
Household attributes								
nº of household members	-0.011	-0.0001	-0.036	-0.0035	-0.005	-0.0003	-0.0105	-0.0011
nº of children (4- years)	-0.312***	-0.0356***	-0.314***	-0.0388***	-0.304***	-0.0342***	-0.304***	-0.0341***
nº of teenagers (4-16 years)	-0.130**	-0.0185***	-0.131**	-0.0204***	-0.123**	-0.0175***	-0.109*	-0.0148**
Professional status								
Unemployed (reference)								
Business owner	-0.738***	-0.0705***	-0.647***	-0.0655***	-0.685***	-0.0637***	-0.667***	-0.0603***
Corporate member	-0.280	-0.0314	-0.026	-0.0084	-0.912	-0.0264	-0.187	-0.0215
Family business	-0.098	-0.0038	-0.082	-0.0082	0.000	0.0155	-0.0238	-0.0139
Full-time worker	-0.142	-0.0009	-0.124	-0.0011	-0.089	-0.0063	-0.0788	-0.0069
Part-time worker	-0.132	-0.0004	-0.129	-0.0079	-0.019	-0.0179	-0.0083	-0.0174
Others	-0.057	-0.0201	-0.131	-0.0179	-0.127	-0.0121	-0.0779	-0.0165
Educational level								
Low (reference)								
Medium	0.194***	0.0249***	0.244***	0.0330***	0.151**	0.0205***	0.134*	0.0161**
High	0.324***	0.0268***	0.418***	0.0410***	0.225***	0.0171**	0.222**	0.0137**
Driver's license (reference = no license)	-0.805***	-0.0630***	-0.792***	-0.0634***	-0.843***	-0.0659***	-0.862***	-0.0670***
Car ownership (reference = no car)	-1.983***	-0.1781***	-1.991***	-0.1886***	-1.981***	-0.1732***	-1.975***	-0.1749***
Motorcycle license (reference = no license)	-0.228***	-0.0316***	-0.216**	-0.0346***	-0.277***	-0.0376***	-0.277***	-0.0373***
Motorcycle ownership (reference = no motorcycle)	-1.587***	-0.0997***	-1.524***	-0.0996***	-1.593***	-0.0983***	-1.604***	-0.0978***
Activity duration	0.007***	0.0021***	0.006***	0.0023***	0.0063***	0.0019***	0.0064***	0.0012***
Level 2 Built environment attributes								
Employment density	-0.000***	-0.0000***						
Land-use mix	1.359***	0.1426***						
Distance to the nearest public-transit station	-0.022	-0.0031						
Number of public-transit stations	0.076***	0.0061***						
Distance to the nearest highway entrance/exit	-0.065***	-0.0072***						
Δ Distance to the nearest highway entrance/exit (infrastructure improvements 1991-2001)	0.001	0.0018*						
Presence of urban amenities	0.248***	0.0212***						

TABLE 7.6 Multilevel multinomial logit models for work-trip purposes (reference category = private transportation)

	ALTERNATIVE CATEGORY (3) = BICYCLING AND WALKING							
	MODEL 1: ISC-BE		MODEL 2: ISC-P1		MODEL 3: ISC-P2		MODEL 4: ISC-P3	
	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME
	0.457***	0.0340***	0.448***	0.0343***	0.445***	0.0365***	0.395***	0.0274***
	-0.204**	-0.0077	-0.217**	-0.0081	-0.195**	-0.0081	-0.215**	-0.0113
	-0.113	-0.0028	-0.109	-0.0003	-0.101	-0.0023	-0.077	-0.0001
	0.116	0.0101	0.107	0.0095	-0.110	-0.0101	0.103	0.0078
	0.339***	0.0350**	0.335***	0.0362**	0.322***	0.0343**	0.298**	0.0289*
	1.082***	0.1216***	1.101***	0.1297***	1.016***	0.1207***	1.052***	0.1155***
	-0.026	-0.0028	-0.021	-0.0008	-0.189	-0.0022	-0.000	-0.0004
	-0.030	-0.0117	-0.037	0.0129	-0.029	-0.0114	-0.017	-0.0122
	0.061	0.0145**	0.059	0.0159**	0.060	0.0142**	0.047	0.0112*
	-0.202	-0.0084	-0.225	-0.0032	-0.198	-0.0060	-0.221	-0.0016
	-0.030	-0.0110	0.074	0.0137	0.073	0.0221	0.003	0.0103
	-0.296	-0.0351	-0.313	-0.0412	-0.286	-0.0402	-0.333	-0.0428
	-0.308***	-0.0344***	-0.309***	-0.0377***	-0.317***	-0.0398***	-0.321***	-0.0387***
	-0.404***	-0.0469***	-0.420***	-0.0530***	-0.383***	-0.0517***	-0.370***	-0.0480***
	-0.530*	-0.0652**	-0.609*	-0.0768**	-0.534*	-0.0650*	-0.532*	-0.0639*
	-0.037	-0.0143*	-0.024	-0.0173**	-0.055	-0.0148*	-0.017	-0.0084
	0.230***	0.0141**	0.234***	0.0089*	0.181**	0.0132**	0.244***	0.0210**
	-0.775***	-0.0686***	-0.786***	-0.0736***	-0.777***	-0.0696***	-0.810***	-0.0697***
	-1.854***	-0.1845***	-1.866***	-0.1900***	-1.850***	-0.1915***	-1.828***	-0.1761***
	0.102	0.0249**	0.119	0.0298***	0.115	0.0299***	0.128	0.0298***
	-1.729***	-0.1192***	-1.749***	-0.1298***	-1.733***	-0.1243***	-1.785***	-0.1246***
	-0.026***	-0.0037***	-0.024***	-0.0038***	-0.024***	-0.0035***	-0.011***	-0.0017***
	-0.000***	-0.0000***						
	0.380	0.0187						
	0.010	0.0025						
	0.058***	0.0036**						
	-0.010	0.0019						
	-0.033***	-0.0044**						
	0.164***	0.0088**						

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RANDOM INTERCEPT MODELS DETERMINANTS OF TRAVEL MODE CHOICE: WORK-TRIP PURPOSES	ALTERNATIVE CATEGORY (2) = PUBLIC TRANSPORTATION							
	MODEL 1: ISC-BE		MODEL 2: ISC-P1		MODEL 3: ISC-P2		MODEL 4: ISC-P3	
	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME
Level 2 Polycentricity: proximity to centers								
Distance to Barcelona (central city)			-0.075***	-0.0083***				
Distance to the nearest secondary center (inverse)			0.089**	0.0161**				
Level 2 Polycentricity: size of centers								
Origin: peripheral areas (reference)								
Origin: central city (Barcelona)					1.528***	0.1416***		
Origin: secondary centers					0.813***	0.0571***		
Origin: centers' neighboring areas					0.167	0.0079		
Destination: peripheral areas (reference)								
Destination: central city (Barcelona)					1.674***	0.2065***		
Destination: secondary centers					0.599***	0.0851***		
Destination: centers' neighboring areas					0.215***	0.0354***		
Level 2 Polycentricity: aggregate size of centers through their integration								
Peripheral areas to peripheral areas (reference)								
Central city to central city							3.450***	0.3744***
Central city to secondary centers							2.494***	0.2927***
Central city to centers' neighboring areas							2.251***	0.2735***
Central city to peripheral areas							2.282***	0.2862***
Secondary centers to central city							2.898***	0.3398***
Secondary centers to secondary centers							1.579***	0.0998***
Secondary centers to centers' neighboring areas							1.279***	0.1367***
Secondary centers to peripheral areas							0.632*	0.0927***
Centers' neighboring areas to central city							1.913***	0.1908***
Centers' neighboring areas to secondary centers							1.184***	0.1434***
Centers' neighboring areas to centers' neighboring areas							0.463**	0.0247***
Centers' neighboring areas to peripheral areas							0.681**	0.1005***
Peripheral areas to central city							2.025***	0.2361***
Peripheral areas to secondary centers							0.764***	0.0109***
Peripheral areas to centers' neighboring areas							0.238	0.0604***
Intercept	-0.782**		2.033***		-0.952***		-1.197***	
Random part								
Variance at level 2 (municipalities)	0.286*** (0.0493)		0.463*** (0.0684)		0.224*** (0.0421)		0.259*** (0.0432)	
Number of observations	12,006		12,006		12,006		12,006	
L (β) model	-8623.23		-8657.03		-8409.74		-8080.97	
AIC (Akaike Information Criterion)	17369.67		17416.06		16937.48		16315.96	
BIC (Bayesian Information Criterion)	17820.65		17793.11		17373.68		16885.23	

TABLE 7.6 Multilevel multinomial logit models for work-trip purposes (reference category = private transportation)

****, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1), respectively. Standard errors of the random part are reported in parentheses. Note(s): AME, average marginal effects. AME for categorical variables is the discrete change from the reference category. The intercept-only model holds a β coefficient of -1.16*** (public transportation) and -1.26*** (bicycling and walking). The random term in this model (0.801 with a std. err. of 0.052) is significant. Models 1-4 represent an improvement to the baseline model (model 0: ISC) which is estimated by only considering individual-specific attributes (results available on request).*

	ALTERNATIVE CATEGORY (3) = BICYCLING AND WALKING							
	MODEL 1: ISC-BE		MODEL 2: ISC-P1		MODEL 3: ISC-P2		MODEL 4: ISC-P3	
	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME
			-0.025***	-0.0007**				
			0.077**	0.0161**				
					1.012***	0.0595***		
					0.752***	0.0643***		
					0.236*	0.0228*		
					-0.112***	-0.1108***		
					-0.609***	-0.1144***		
					-0.408***	-0.0703***		
							0.665***	0.0927***
							-0.791***	-0.2058***
							-1.335***	-0.2368***
							-1.615***	-0.2531***
							-0.313*	-0.1806***
							0.300**	0.0746**
							-1.264***	-0.1999***
							-2.392***	-0.2575***
							-0.563***	-0.1547***
							-1.944***	-0.2448***
							-0.094	-0.0264
							-2.647***	-0.2681***
							-1.250***	-0.2237***
							-2.676***	-0.2700***
							-2.523***	-0.2586***
	0.858***		2.144***		1.276***		1.335***	
	0.286*** (0.0493)		0.463*** (0.0684)		0.224*** (0.0421)		0.259*** (0.0432)	
	12,006		12,006		12,006		12,006	
	-8623.23		-8657.03		-8409.74		-8080.97	
	17369.67		17416.06		16937.48		16315.96	
	17820.65		17793.11		17373.68		16885.23	

RANDOM INTERCEPT MODELS DETERMINANTS OF TRAVEL MODE CHOICE: NON-WORK TRIP PURPOSES	ALTERNATIVE CATEGORY (2) = PUBLIC TRANSPORTATION							
	MODEL 1: ISC-BE		MODEL 2: ISC-P1		MODEL 3: ISC-P2		MODEL 4: ISC-P3	
	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME
Fixed part								
Level 1 Individual-specific characteristics								
Gender (reference = male)	0.240***	0.0173***	0.253***	0.0205***	0.261***	0.0198***	0.252***	0.0211***
Age cohorts								
36-45 years (reference)								
16-25 years	-0.001	-0.0204**	-0.000	-0.0181**	0.020	0.0227**	0.014	0.0166*
26-35 years	-0.071	-0.0039	-0.085	-0.0067	-0.053	-0.0022	-0.051	-0.0026
46-55 years	0.123	0.0046	0.114	0.0043	0.108	0.0021	0.124	0.0065
56-65 years	0.253***	0.0078	0.255***	0.0034	0.237***	0.0095	0.251***	0.0015
65+ years	0.395***	0.0138	0.415***	0.0037	0.390***	0.0148	0.400***	0.0007
Household attributes								
nº of household members	-0.044**	-0.0024	-0.054***	-0.0044*	-0.019	-0.0004	-0.027	-0.0019
nº of children (4- years)	-0.157**	-0.0322***	-0.153**	-0.0294***	-0.143*	-0.0306***	-0.135*	-0.0269***
nº of teenagers (4-16 years)	-0.154***	-0.0255***	-0.160***	-0.0256***	-0.142***	-0.0240***	-0.134***	-0.0215***
Professional status								
Unemployed (reference)								
Business owner	-1.175***	-0.0795***	-1.115***	-0.0756***	-1.091***	-0.0695***	-1.101***	-0.0733***
Corporate member	-0.773**	-0.0485	-0.733**	-0.0475	-0.714*	-0.0459	-0.736**	-0.0496
Family business	-0.446*	-0.0141	-0.478*	-0.0007	-0.462*	-0.0114	-0.481*	-0.0019
Full-time worker	-0.675***	-0.0037	-0.667***	-0.0121*	-0.609***	-0.0042	-0.617***	-0.0021
Part-time worker	-0.437***	-0.0170	-0.447***	-0.0072	-0.440***	-0.0159	-0.436***	-0.0113
Others	-0.615***	-0.0153	-0.602**	-0.0200	-0.592**	-0.0137	-0.586**	-0.0185
Educational level								
Low (reference)								
Medium	0.113**	0.0326***	0.130***	0.0332***	0.073	0.0280***	0.052	0.0205***
High	0.253***	0.0366***	0.298***	0.0451***	0.162**	0.0274***	0.158**	0.0200**
Driver's license (reference = no license)	-0.573***	-0.0408***	-0.563***	-0.0416***	-0.592***	-0.0428***	-0.597***	-0.0431***
Car ownership (reference = no car)	-1.710***	-0.1340***	-1.705***	-0.1445***	-1.635***	-0.1222***	-1.643***	-0.1286***
Motorcycle license (reference = no license)	-0.144**	-0.0209**	-0.131*	-0.0185**	-0.132*	-0.0202**	-0.139**	-0.0209**
Motorcycle ownership (reference = no motorcycle)	-1.367***	-0.0830***	-1.340***	-0.0838***	-1.412***	-0.0859***	-1.412***	-0.0845***
Activity duration	0.013***	0.0031***	0.013***	0.0028***	0.0148***	0.0033***	0.0145***	0.0021***
Level 2 Built environment attributes								
Employment density	-0.000***	-0.0000***						
Land-use mix	0.365	0.0323						
Distance to the nearest public-transit station	-0.052**	-0.0088***						
Number of public-transit stations	0.059**	0.0018*						
Distance to the nearest highway entrance/exit	-0.041*	-0.0056***						
Δ Distance to the nearest highway entrance/exit (infrastructure improvements 1991-2001)	0.026**	0.0053***						
Presence of urban amenities	0.197**	0.0267***						

TABLE 7.7 Multilevel multinomial logit models non-work trip purposes (reference category = private transportation)

	ALTERNATIVE CATEGORY (3) = BICYCLING AND WALKING							
	MODEL 1: ISC-BE		MODEL 2: ISC-P1		MODEL 3: ISC-P2		MODEL 4: ISC-P3	
	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME
	0.200***	0.0165***	0.193***	0.0152**	0.201***	0.0151**	0.170***	0.0093*
	-0.266***	-0.0463***	-0.270***	-0.0449***	-0.258***	-0.0466***	-0.212***	-0.0350***
	-0.075	-0.0079	-0.069	-0.0060	-0.066	-0.0076	-0.058	-0.0059
	0.156**	0.0185*	0.157**	0.0192*	0.159**	0.0204*	0.138**	0.0137
	0.517***	0.0747***	0.512***	0.0735***	0.507***	0.0753***	0.466***	0.0596***
	0.794***	0.1174***	0.782***	0.1118***	0.797***	0.1187***	0.702***	0.0886***
	-0.045**	-0.0045	-0.039**	-0.0029	-0.038**	-0.0052*	-0.022	-0.0016
	0.130**	0.0356***	0.126**	0.0323***	0.139**	0.0360***	0.127**	0.0301***
	0.052	0.0216***	0.057	0.0211***	0.058	0.0216***	0.052	0.0182***
	-0.936***	-0.0938***	-0.967***	-0.0108***	-0.912***	-0.0957***	-0.917***	-0.0851***
	-0.679**	-0.0713	-0.680**	-0.0781*	-0.593**	-0.0599	-0.611**	-0.0543
	-0.919***	-0.1402***	-0.915***	-0.1359***	-0.915***	-0.1389***	-0.890***	-0.1192***
	-1.130***	-0.1607***	-1.136***	-0.1610***	-1.105***	-0.1618***	-1.109***	-0.1461***
	-0.941***	-0.1448***	-0.947***	-0.1432***	-0.933***	-0.1437***	-0.937***	-0.1300***
	-0.847***	-0.1146***	-0.854***	-0.1175***	-0.818***	-0.1117***	-0.793***	-0.0959***
	-0.206***	-0.0459***	-0.216***	-0.0462***	-0.223***	-0.0456***	-0.188***	-0.0340***
	-0.010	-0.0231**	-0.052	-0.0312***	-0.059	-0.0240**	0.0131	0.0095
	-0.503***	-0.0460***	-0.518***	-0.0520***	-0.504***	-0.0450***	-0.524***	-0.0435***
	-1.503***	-0.1602***	-1.499***	-0.1691***	-1.493***	-0.1647***	-1.471***	-0.1432***
	0.016	0.0142	0.019	0.0123	0.032	0.0160*	0.040	0.0164*
	-1.390***	-0.1388***	-1.420***	-0.1455***	-1.400***	-0.1391***	-1.469***	-0.1389***
	-0.016***	-0.0039***	-0.016***	-0.0037***	-0.016***	-0.0040***	-0.003**	-0.0015***
	-0.000	-0.0000						
	0.226	0.0107						
	0.019	0.0077***						
	0.079***	0.0092***						
	-0.000	-0.0031						
	-0.021**	-0.0059***						
	0.0076	0.0145**						

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RANDOM INTERCEPT MODELS DETERMINANTS OF TRAVEL MODE CHOICE: NON-WORK TRIP PURPOSES	ALTERNATIVE CATEGORY (2) = PUBLIC TRANSPORTATION							
	MODEL 1: ISC-BE		MODEL 2: ISC-P1		MODEL 3: ISC-P2		MODEL 4: ISC-P3	
	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME
Level 2 Polycentricity: proximity to centers								
Distance to Barcelona (central city)			-0.039***	-0.0063***				
Distance to the nearest secondary center (inverse)			0.316***	0.0512***				
Level 2 Polycentricity: size of centers								
Origin: peripheral areas (reference)								
Origin: central city (Barcelona)					1.476***	0.2100***		
Origin: secondary centers					0.332**	0.0761***		
Origin: centers' neighboring areas					0.036***	0.0281***		
Destination: peripheral areas (reference)								
Destination: central city (Barcelona)					1.198***	0.1378***		
Destination: secondary centers					0.619***	0.0627***		
Destination: centers' neighboring areas					0.388***	0.0344***		
Level 2 Polycentricity: aggregate size of centers through their integration								
Peripheral areas to peripheral areas (reference)								
Central city to central city							2.964***	0.3669***
Central city to secondary centers							2.521***	0.3939***
Central city to centers' neighboring areas							2.154***	0.3118***
Central city to peripheral areas							1.936***	0.3472***
Secondary centers to central city							1.941***	0.3313***
Secondary centers to secondary centers							1.193***	0.1048***
Secondary centers to centers' neighboring areas							1.161***	0.2453***
Secondary centers to peripheral areas							0.468**	0.1754***
Centers' neighboring areas to central city							1.598***	0.3164***
Centers' neighboring areas to secondary centers							0.965***	0.2172***
Centers' neighboring areas to centers' neighboring areas							0.476***	0.0279***
Centers' neighboring areas to peripheral areas							0.213	0.1303***
Peripheral areas to central city							1.708***	0.2872***
Peripheral areas to secondary centers							0.532***	0.1942***
Peripheral areas to centers' neighboring areas							0.491***	0.1644***
Intercept	0.015**		0.880***		-0.745***		-0.976***	
Random part								
Variance at level 2 (municipalities)	0.205*** (0.0453)		0.231*** (0.0470)		0.248*** (0.0512)		0.241*** (0.0483)	
Number of observations	22,478		22,478		22,478		22,478	
L (β) model	-17906.04		-17979.23		-17747.32		-16687.10	
AIC (Akaike Information Criterion)	35934.08		36060.46		35612.64		33528.20	
BIC (Bayesian Information Criterion)	36423.32		36469.50		36085.84		34145.76	

TABLE 7.7 Multilevel multinomial logit models non-work trip purposes (reference category = private transportation)

****, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1), respectively. Standard errors of the random part are reported in parentheses. Note(s): AME, average marginal effects. AME for categorical variables is the discrete change from the reference category. The intercept-only model holds a β coefficient of -0.70*** (public transportation) and -0.27*** (bicycling and walking). The random term in this model (0.345 with a std. err. of 0.058) is significant. Models 1-4 represent an improvement to the baseline model (model 0: ISC), which is estimated by only considering individual-specific attributes (results available on request).*

	ALTERNATIVE CATEGORY (3) = BICYCLING AND WALKING							
	MODEL 1: ISC-BE		MODEL 2: ISC-P1		MODEL 3: ISC-P2		MODEL 4: ISC-P3	
	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME	COEF. (B)	AME
			-0.013***	-0.0051***				
			0.124**	0.0435**				
					0.023	0.1252***		
					-0.537***	-0.1201***		
					-0.382***	-0.0719***		
					0.387***	0.0277**		
					0.225***	0.0060*		
					0.185***	0.0048*		
							0.245***	0.2081***
							-0.762**	-0.3336***
							-0.696**	-0.2852***
							-1.581***	-0.3939***
							-1.366***	-0.3666***
							0.186***	0.0973***
							-2.219***	-0.4143***
							-3.227***	-0.4690***
							-2.111***	-0.4270***
							-2.302***	-0.4128***
							-0.027	-0.0229
							-2.837***	-0.4332***
							-1.369***	-0.3485***
							-3.656***	-0.4928***
							-2.749***	-0.4347***
	1.737***		1.596***		2.028***		2.048***	
	0.205*** (0.0453)		0.231*** (0.0470)		0.248*** (0.0512)		0.241*** (0.0483)	
	22,478		22,478		22,478		22,478	
	-17906.04		-17979.23		-17747.32		-16687.10	
	35934.08		36060.46		35612.64		33528.20	
	36423.32		36469.50		36085.84		34145.76	

Among the individual-specific characteristics, car ownership has the strongest relationship to travel mode choice. Having a car increases the likelihood of the use of private transportation instead of public transportation from 17.32% to 18.86% (depending on the model specification) and of bicycling-walking from 17.16% to 19.15%. This effect is expected because car ownership might also indirectly account for the income-level effects, which this research was not able to consider due to data limitations. Additionally, it is worth noting the effects of being female, which in the best case increases the probability of taking public transportation (bicycling-walking) instead of private transportation by 4.44% (3.65%), and having a high educational level relative to a low educational level, which increases probability of taking public transportation or bicycling-walking by 4.10% and 2.10%, respectively.

The effects of individual-specific attributes on non-work trips are reported in Table 7.7. Signs and significance levels on most of the explanatory variables in the non-work trip models remain the same compared to the estimates from the models for work trips. However, the magnitude of the AMEs shrinks notably in some trip makers' attributes (e.g., car ownership or having a driver's license) indicating that their role in affecting individuals' mode choice is less important for non-work trips. Moreover, one primary difference can be noted. Now, professional status appears to be a stronger predictor. Specifically, being a business owner (or having a full-time job) has the greatest influence on increasing the probability of taking private transportation instead of public transportation (or bicycling-walking). Whereas being a business owner instead of being unemployed increases the probability of using private transportation from 6.95% to 7.95% depending on the model considered, having a full-time job increases this probability from 14.61% to 16.18%. These findings are consistent with Cervero and Kockelman (1997) and Vega and Reynolds-Feighan (2008), who also have found that full-time workers and a higher professional status encourage the use of private transportation, but they are inconsistent with Cervero (2002) and Commins and Nolan (2011).

The role played by built environment attributes

With built environment attributes included in the first model specification (model 1: ISC-BE) for both work (Table 7.6) and non-work trips (Table 7.7), those attributes' effects on travel mode choice can be discussed. Generally, the effects of built environment attributes on individuals' decisions are relatively modest, although this is less obvious for work trips. Moreover, some of the built environment attributes either do not present the expected sign (e.g., density, distance to the nearest highway entrance/exit) or are not statistically significant (e.g., land-use mix for non-work trips).

With respect to those built environment attributes that are both significant and have the expected sign, the following points can be observed. Land-use mix appears to be an important predictor of taking public transportation instead of private transportation for work trips. A greater mix of land uses increases the probability of using public transportation compared to private transportation by 14.26% for every point increase above the average in the degree of land-use mix held by a municipality. This AME is quite similar to the one found (12%) in the meta-analysis carried out by Ewing and Cervero (2010). Additionally, the greater the number of public-transit (train and metro) stations, the higher the probability of using public transportation or bicycling-walking instead of private transportation. However, the effects of the number of stations are small for both work and non-work trips. For each additional public-transit station in a municipality, the relative probability of using public transportation (bicycling-walking) increases by 0.61% (0.36%) for work trips and 0.18% (0.92%) for non-work trips. The role played by proximity to public-transit stations and highway infrastructure improvements is only significant with the expected sign for non-work trips and when the alternative is public transportation. Nevertheless, the effects of these two built environment attributes are very modest. For each kilometer closer to a public-transit station, the relative probability of taking public transportation instead of private transportation is increased by 0.8%. Each kilometer closer to highway-network access decreases the probability of using public transportation instead of private transportation by 0.5%. Finally, whereas urban amenities encourage the use of public transportation compared to private transportation by 2.67% (work trips) and 2.12% (non-work trips) for every point increase above the average in the amenity index score, the effects of amenities (0.8%) are only statistically significant for increasing the use of bicycling-walking for work trips.

The multiple effects of polycentricity

The effects of proximity to centers, the effects of the size of centers at both a trip's origin and its destination, and the effects of the aggregate size of centers through their integration are statistically significant for both work and non-work travel. Additionally, the considerable magnitude (with the expected sign) of most of these three effects of polycentricity illustrate that polycentricity not only is strong predictor of travel mode choice but also leads to more sustainable mode choices. This reinforces the hypothesis that polycentricity affects individuals' decisions on travel mode choice by encouraging them to switch from private transportation to either public transportation or bicycling-walking.

Effects of proximity to centers

As regards the effects of proximity to centers (model 2: ISC-P1) for work and non-work trips (Tables 7.6-7.7), the results reveal that greater proximity to the central city and the nearest secondary center reduces the relative probability of taking private transportation instead of the alternatives. This empirically substantiates the role played by the effects of proximity (access) to centers' agglomeration economies in encouraging individuals to make more sustainable travel mode choices. Compared to people who live further away, people living in areas close to centers are more influenced by the agglomeration benefits that stem from centers' size (e.g., greater accessibility to several types of jobs and amenities), which in turn supports public transportation and slow modes because more people would be persuaded to travel toward centers to perform their daily activities. In particular, for each kilometer that an individual lives from his or her nearest secondary center, the relative probability that he or she takes private transportation instead of public transportation (bicycling-walking) increases by 1.6% (1.6%) and 5.12% (4.35%) for work and non-work trips, respectively. However, the effects of proximity to the central city are more modest. In this case, the relative probabilities are 0.83% (0.07%) and 0.63% (0.51%) for work and non-work trips, respectively.

Effects of the size of centers

With respect to the effects of the size of centers, which can also proxy for the influence of built environment attributes (as discussed above) on both trip origin and destination (model 3: ISC-P2), it can be noted, as one might expect, that the magnitude of the impact of size on travel mode choice is larger than the effects of proximity to centers. The estimates indicate that people living in (trip origin) or traveling to (trip destination) of the central city and secondary centers are more likely to take public transportation instead of private transportation for work trips compared to people living or traveling to peripheral areas. For each trip that begins in the central city or secondary centers, the probability of using public transportation instead of private transportation increases by 14.16% and 5.71%, respectively, compared to when trips begin in peripheral areas. Likewise, for each trip that ends in the central city or secondary centers the probability of using public transportation increases by 20.65% and 8.51%, respectively, compared to when trips end in peripheral areas. In addition, it seems that individuals traveling to centers' neighboring areas seem to enjoy somewhat of a benefit from these areas' geographical proximity to centers. Trips that end in municipalities adjacent to centers also increase (3.54%) a person's propensity to take public transportation compared to trips that end in peripheral areas.

Interestingly, the effects of centers' size are even larger with respect to non-work trips. Additionally, the effects of centers' neighboring areas have become statistically significant not only for trip destination but also for trip origin. Currently, the AME of a trip originating in the central city, secondary centers and centers' neighboring areas compared to peripheral areas are 21.00%, 7.61% and 2.81%, respectively. Likewise, the AME of a trip destination in the central city, secondary centers and centers' neighboring areas compared to peripheral areas are 13.78%, 6.27% and 3.44%, respectively. This may indicate that travel mode choice is more dependent on the built environment characteristics of centers (that is, central city and secondary centers) than the built environment characteristics of centers' neighboring areas and peripheral areas. Put differently, these AMEs could reveal that individuals' travel mode decisions are strongly influenced by centers' built environment attributes (e.g., the presence of mixed-land uses, accessibility to amenities, etc.), which can indeed be understood as indicators of agglomeration benefits stemming from their size, as was discussed above. Consequently, this could explain why this study has previously found that the attributes of the built environment have only modest effects on travel mode choice in general. Whereas the built environment attributes of centers may be important factors in individuals' travel mode choices, the built environment attributes of other urban areas (e.g., peripheral areas) may have a weaker effect and thus, when this different role played by places' built environment attributes in relation to the metropolitan (polycentric) spatial structure is not distinguished, the built environment will have (on average) little effect. Finally, it is important to stress that when a trip's origin and destination are in a center (as opposed to a peripheral area), bicycling-walking seems to compete with private transportation much less than public transportation competes with private transportation. Note that when bicycling-walking is considered as an alternative mode, either centers' AMEs are lower for work and non-work trips or even their effects are negative or insignificant (e.g., at trip origin for non-work trips).

Effects of the aggregate size of centers through their integration

Considering the effects of the aggregate size of centers through their integration (model 4: ISC-P3), five main findings can be noted. First, the magnitude of the impact of aggregate size on individuals' travel mode choice is generally larger than the individual-specific characteristics of the trip maker and the other two polycentricity effects considered in this study. Second, of all functional linkages, the functional linkages between centers (central city and secondary centers) appear to be the inter-municipal relationship that most increases the propensity to take public transportation instead of private transportation both for work and non-work trips. For each work (non-work) trip made from the central city to secondary centers and from secondary centers to the central city, the probability of using public transportation rises by 29.27% (39.39%) and 33.98% (33.13%), respectively, compared to when a trip is made from peripheral areas to peripheral areas. Third, the use of public transportation is much more encouraged by trips that involve intra-center relationships (central-city-to-central-city and secondary-centers-to-secondary-centers trips) than by trips among centers' neighboring areas or peripheral areas. Fourth, public transportation is more likely to be used for trips from centers' neighboring areas to centers than for trips from centers' neighboring areas to peripheral areas. For each work trip made from centers' neighboring areas to the central city, the propensity to take public transportation increases by 19.08%, which increases to 31.64% for non-work trips. The corresponding figures for each trip from centers' neighboring areas to secondary centers are slightly lower—14.34% (work trips) and 21.72% (non-work trips), respectively—and they are much lower for each trip from centers' neighboring areas to peripheral areas (10.05% for work trips and 13.03% for non-work trips). Fifth, for inter-municipal trips, bicycling-walking is much less competitive with private transportation than public transportation is with private transportation. Only central-city-to-central-city and secondary-centers-to-secondary-centers trips increase the probability of bicycling-walking instead

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of taking private transportation. Note that for all other inter-municipal relationships, β coefficients have a negative sign, thus indicating that individuals prefer to take private transportation instead of bicycling-walking. This result was obviously expected because inter-municipal relationships such as central city-to-peripheral-areas imply a trip distance that renders walking or bicycling not feasible.

Interaction analysis between the built environment and polycentricity

The previous two subsections have shown that in general, the effects of built environment attributes on individuals' travel mode choices are fairly modest, which can be explained by the fact that individuals are more strongly influenced by the built environment attributes of centers than by those of other types of cities. This key result merits further discussion because it also may point to a broader and major finding. Individuals' travel behavior is becoming more connected to the metropolitan structure, and in particular, the existence of a polycentric pattern. To examine the interaction effects between built environment and polycentricity in detail, this study estimates more multilevel multinomial logit models for work and non-work travel. These models combine the specification of built environment attributes (model 1: ISC-BE) with each of the three model specifications of the effects of polycentricity (model 2: ISC-P1, model 3: ISC-P2, and model 4: ISC-P3). Figure 7.4 presents examples of the AME of built environment attributes on travel mode choice that operates through polycentricity. These examples focus on some of the most relevant AMEs of employment density and the presence of urban amenities (e.g., the AME of employment density for work travel that operates through the effects of the size of centers), whereas other AMEs of built environment attributes (e.g., land-use mix) are available on request.

The effect of employment density on travel mode choice is now statistically significant with the expected positive sign for work and non-work travel. The magnitude of employment density's AME shrinks notably as distance to the central city (Figure 7.4a) and distance to the nearest secondary center (available on request) increases. That means that fostering densification in urban areas near centers, for example, within a radius of 5 km, will result in a greater increase in the probability that an individual will take public transportation (or it will result in a greater decrease in the probability of taking private transportation) than will promoting densification in urban areas located further away from centers. For instance, the AME of employment density on public transportation is 0.04 (or -0.06 for private transportation) at 5 km from the central city, whereas it is 0.02 (or -0.055 for private transportation) at 30 km. Similarly as the AME of employment density, the effect of urban amenities on the probability of encouraging/discouraging individuals to use public/private transportation for work and non-work travel decrease with distance to the central city (available on request) and distance to the nearest secondary center (Figure 7.4b). Furthermore, Figure 7.4 reveals that the AME of built environment attributes on travel mode choice are not solely dependent on the effects of proximity to centers. The effects of the size of centers at both trip origin and trip destination and the effects of the aggregate size of centers through their integration are also significant. For example, the AME of employment density on public transportation for work trips is higher when these trips end in the central city (0.068) and in secondary centers (0.048) than when these trips end in centers' neighboring areas (0.033) and peripheral areas (0.025) (see Figure 7.4c). In addition, the magnitude of the AME of employment density with respect to encouraging/discouraging individuals to use (or from using) public/private transportation is notably higher for trips among centers, as Figure 4.7d reveals. Whereas the AME of job density on the probability of increasing the use of public transportation is 0.063 and 0.035 for central-city-to-central-city and secondary-centers-to-secondary-centers trips, respectively, these AMEs are 0.02 and 0.015 for centers'-neighboring-areas-to-centers'-neighboring areas and peripheral-areas-to-peripheral-areas trips, respectively. The corresponding AME of job density on the probability of decreasing the use of private transportation is -0.035 and -0.029 for trips that start and end in the central city and for trips among secondary centers, respectively, whereas that AME is slightly lower for trips among centers' neighboring areas (-0.021) and among peripheral areas (-0.02).

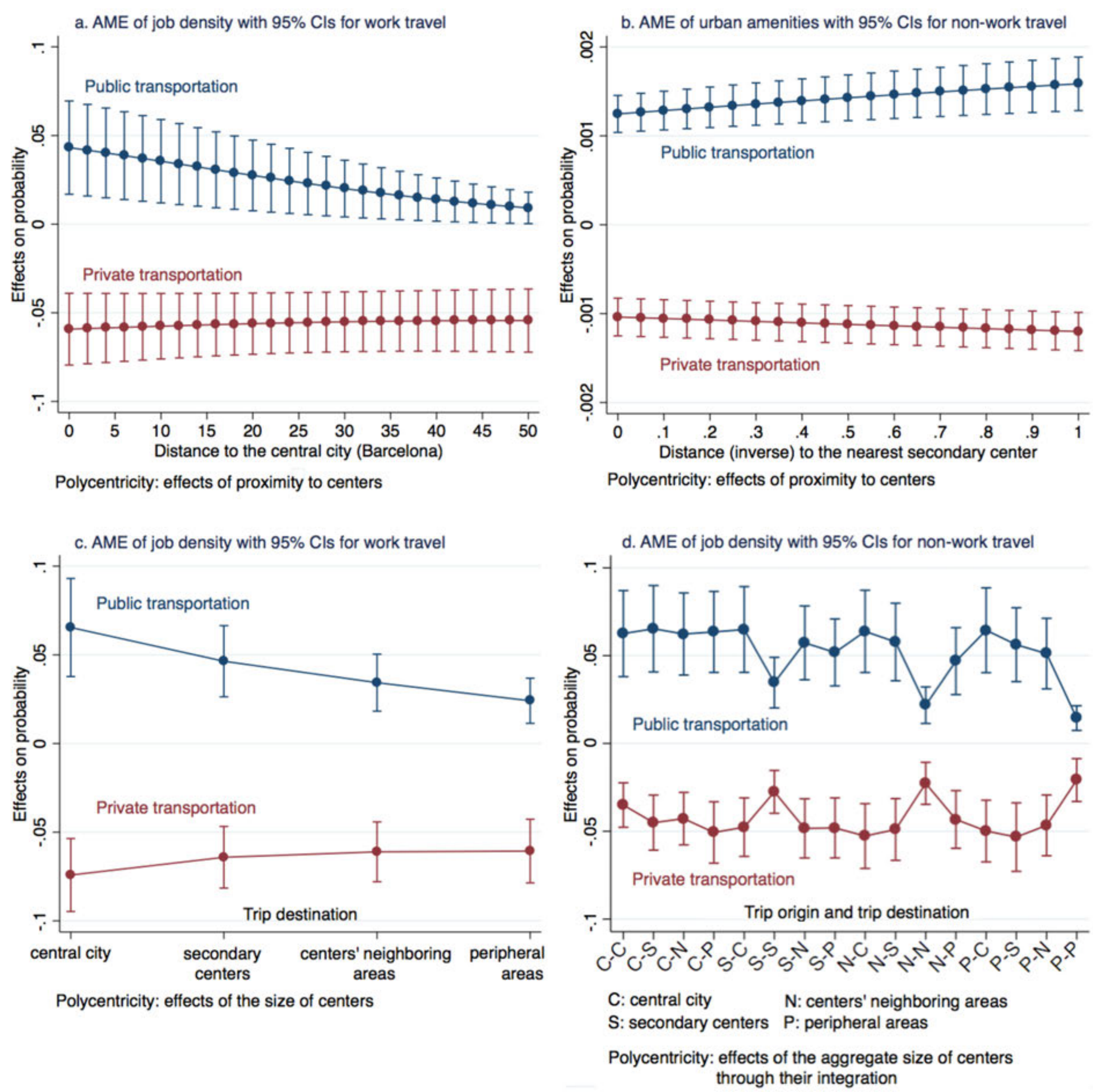

FIGURE 7.4 Average marginal effects of built environment attributes with 95% confidence intervals on travel mode choice via polycentricity

These results regarding the AME of the built environment on travel mode choice for work and non-work trips empirically substantiate the notion that the effects of built environment attributes depend on the urban structure of metropolitan areas. This key finding supports the idea of promoting compact-city strategies and transit-oriented development that efficiently serve not only centers (central city and secondary centers) but also their neighboring municipalities. Moreover, promoting these planning-policy solutions also fosters a higher level of spatial integration not only among centers but also between them and their surrounding areas, which is desirable for enhancing environmental sustainability in the Barcelona metropolitan region.

Individual non-work trip purposes

Although until now, attention has been paid to work-related trips and the broad category of 'non-work trips', similar analyses can be performed examining the purpose of each individual non-work trip (shopping, leisure, education, social-visit, and health trips). Doing so results in findings that are largely similar: the signs and significance levels on most of the determinants regarding individual-specific characteristics, built environment attributes and polycentricity remain the same. However, with respect to the magnitude of polycentricity's effects on travel mode choice, some interesting nuances can be noted. The effects of proximity to centers seem to be more important for education and shopping trips. With regard to these trip purposes, both public transportation and bicycling-walking are remarkably competitive with private transportation. For example, for each kilometer that an individual lives from his or her nearest secondary center, the relative probability that he or she takes private transportation instead of public transportation (bicycling-walking) increases by 9.90% (15.95%) for education trips. The effects of the size of centers appear to be larger for shopping and education trips at trip origin and for shopping and leisure trips at trip destination. For instance, for each shopping trip ending in the central city and in secondary centers, the relative probability of using public transportation increases by 32.9% and 15.73%, respectively, compared to when this trip would have been ended in a peripheral area. These AMEs for a trip destination at the central city and secondary centers are 1.5 and 2 times higher, respectively, than when considering the broad category of 'non-work trips'. Finally, consideration of the effects of the aggregate size of centers through their integration shows that the 'cross-exchange' polycentric interaction pattern is still the one that most increases the propensity to take public transportation. Among the different non-work trip purposes and the distinct primary links taking place in this polycentric interaction pattern (see Figure 7.2b), the highest AME involves education trips between the central city and the secondary centers. That AME is 0.4924 (49.24%), which is 0.0985 (9.85%) more than the AME found when all non-work trips are considered together.

§ 7.7 Conclusion and discussion

This chapter has aimed to examine not only whether the development of multiple centers in the Barcelona metropolitan region since 1991 is influencing the co-location of people, jobs and urban amenities but also whether this polycentric development has encouraged individuals to switch their travel mode choices to be more sustainable. Two research questions guided this twofold research aim. The first question is as follows: To what extent do people living in a center conduct their daily activities in that or another center? In addition, to what extent do people who do not live in a center conduct their daily activities in the center that is closest to them? The second question is as follows: To what extent does polycentricity encourage sustainable travel mode choices, and how can its effects be realized in planning practice? In elaborating these research questions, this study proposed several conceptual and methodological novelties to address the reasons that no consistent answer to these questions has been provided by the literature on polycentricity, co-location and travel mode choice.

First, a more comprehensive and systematic empirical framework was built to unify the fragmented empirical research on the advantages of polycentricity with the aim of achieving broader conclusions on its effects. Instead of a broad definition of a polycentric urban system that does not identify its centers, thus hampering an accurate analysis of the effects of polycentricity, this study has built on the set of centers identified in chapter 5. These centers were identified using a method that accounts for the two pathways (decentralization and incorporation-fusion) in which centers are formed and united in a polycentric configuration. Additionally, it has examined the effects of polycentricity by following the conceptual approach to the link between polycentricity on the intra-urban scale and the performance of metropolitan areas proposed in chapter 2. That means that three distinct dimensions of a polycentric spatial configuration that play a role in the development of agglomeration benefits in a metropolitan area were considered: namely, the size of centers, the (geographic) proximity to centers, and the aggregate size of the centers through their integration. This translates into a framework that examines the sustainability effects of being located in or oriented toward centers, of being located closer to these centers, and of interaction patterns among centers. Second, this chapter considered a wide range of trip purposes—not just commuting—with the aim of increasing current knowledge about how polycentricity influences travel behavior. Third, this chapter has applied an empirical model framework that has not been used in the literature on polycentricity and travel mode choice. More specifically, the estimation of multilevel multinomial logit models has enabled the use of hierarchical data without the drawback of potentially biased estimation results.

The research findings illustrate that Barcelona's polycentric development since 1991 has allowed the co-location of people, jobs, and urban amenities, leading to shorter trip lengths and durations. Most residents of centers performed their daily activities either in those centers or in places close by (i.e., in the centers' neighboring areas). Additionally, most of the jobs and urban functions in centers are filled and used by their own residents or people living close by. These travel patterns translate into shorter average trip distances and trip times for residents of centers (central city and secondary centers) and their neighboring municipalities. The results also show that polycentric development facilitates the growth of non-work trips, which may lead to a greater reduction in travel costs (trip distance and time), especially in centers.

The corroboration of the co-location hypothesis has also prompted this study to make two other important, nuanced points. First, the pathway through which a center emerged matters when economizing travel costs. Centers arising through incorporation-fusion, classified as large centers in accordance with chapter 5, provide their resident populations with a large number of employment and non-work activities, which has increasingly reduced those residents' trip distances and times. This can be explained, as chapters 2 and 5 argued, by the fact that centers resulting from incorporation-fusion have greater urbanization benefits because of their larger city size and more diversified economic structure than do centers resulting from decentralization. Second, the effects of proximity to centers have also played a role in achieving more balanced trip lengths and durations. Residents of centers' neighboring areas (municipalities adjacent to centers) experience increasingly shorter average trip distances and times than do residents of areas that are further out (i.e., peripheral areas).

The empirical analysis of travel mode choice has primarily shown that together with individual-level characteristics, a polycentric structure is a relevant determinant that affects individuals' travel mode choices for both work and non-work-related trips. In contrast, built environment attributes have generally modest effects on travel mode choice, although the results have also revealed that these effects vary somewhat according to which element of the polycentric structure is studied (which type of city, the distance to centers, and which type of interaction). This suggests that individuals' travel behavior is becoming more dependent on the metropolitan structure and in particular, on the existence of a polycentric pattern.

The application of multilevel multinomial logit models explaining the probability of using public transportation or bicycling-walking instead of private transportation indicate that the type of city (i.e., which size have different categories of places: central city, secondary centers, centers' neighboring areas, and peripheral areas) and the type of interaction (i.e., between these four aforementioned categories) exerts a larger effect on travel mode choice than the strongest predictors of individual-specific characteristics (car ownership and professional status for work and non-work trips, respectively) and built environment attributes (land-use mix and the presence of urban amenities for work and non-work trips, respectively). This is not the case for the effects of proximity to centers, but nevertheless, the distance of a place to centers (excluding the central city, i.e., secondary centers) is a stronger factor in determining travel mode choice than most of the trip maker's individual characteristics and all of the built environment attributes when non-work travel is considered, particularly with respect to education and shopping trips. In sum, these findings empirically substantiate the idea that polycentric development can meaningfully influence individuals' travel mode choices in the Barcelona metropolitan region to achieve greater environmental sustainability.

Implications for planning

The research findings from this chapter are important for spatial planning because they inform how the benefits of polycentricity can be realized in planning practice. More specifically, the estimated effects (average marginal effects) of the link between polycentricity and travel mode choice provide evidence-informed knowledge for architects, planners and policymakers upon which policy recommendations for the spatial development of the Barcelona metropolitan region can be based. This study can fill a gap in the 2010 Barcelona Metropolitan Territorial Plan, which did not empirically test the economic, social, and environmental implications of its territorial development strategy, as explained in chapter 4. Three main evidence-informed policy recommendations can be formulated.

First, compact-city strategies and transit-oriented development, which primarily translate into densification and mixed-use development in areas within a half-mile radius around existing or new public-transit stations, are much more effective in terms of encouraging individuals to use public transportation or non-motorized modes when they are implemented in (existing) centers. Therefore, it seems reasonable that policymakers should concentrate foreseen developments in the central city and in the other 12 (secondary) centers identified in chapter 5 to accomplish planning objectives 4 and 13 of the 2010 Barcelona Metropolitan Territorial Plan that state as follows: "… *facilitating the development of public transportation*" and "*providing a greater concentration of public transportation by promoting the nodal structure and compactness of the urban settlement system*" (see Generalitat de Catalunya, 2010).

Second, future urban development (e.g., residential development) can alternatively be located in places adjacent to centers (centers' neighboring areas) because the findings have shown that residents of areas close to centers will then be oriented toward the centers more than to places located further away (e.g., peripheral areas), which in turn may lead them to reduce their travel costs. Additionally, because the findings have revealed that of the inter-municipal relationships that involve places adjacent to centers, the ones that most encourage individuals to take public transportation instead of private transportation involve destinations that are centers (the central city and secondary centers). Policymakers should be aware that the further away from centers new urban development takes place, the lower the probability that individuals will bicycle-walk or use public transportation.

Third, new infrastructure developments and improvements can also be prioritized with the aim of encouraging the greater use of public transportation. In view of the findings, it seems sensible to prioritize the infrastructure proposals of, inter alia, the 2010 Barcelona Metropolitan Territorial Plan (see chapter 4), which most enhance the connectivity within and between centers. Among these infrastructure policy possibilities, it is increasingly clear that the inter-connectivity among secondary centers seems to be a wise strategy because it not only encourages more intensive public transportation usage but also might reduce the congestion related to the accessibility to and from the central city (i.e., radial trips).

In a sense, these three evidence-informed policies shed more light on how the benefits of polycentricity can be realized in planning practice. However, further examination of the association between polycentricity and performance of metropolitan areas is required. Next, chapter 8 addresses the causal links between polycentricity and travel behavior externalities, particularly with respect to trip distance, trip time, and CO_2 emissions from transportation.

8 Polycentricity and travel behavior externalities

§ 8.1 Introduction

The relationship between the built environment and travel behavior externalities has recently become an important topic in the debate among scholars and policymakers about how the negative effects of mobility can be mitigated most effectively. More specifically, scholars and planners—including the advocates of the New Urbanism and Smart Growth movements in the United States and the Compact City in Europe—have argued that travel externalities such as social costs for travelers (e.g., distance traveled) and environmental costs for societal welfare (e.g., transportation-related CO_2 emissions) can be influenced by changing the built environment of urban areas. However, the manner in which the built environment has an impact on travel behavior is complex and to date, the vast empirical knowledge has shown considerable disagreement about the extent of that environment's assumed effects (García-Palomares, 2010; Yang et al., 2012).

In this context, much less is known about whether polycentricity could reduce the negative social and environmental externalities of travel behavior. Indeed, the role played by a polycentric metropolitan structure in mitigating these travel behavior externalities has often presented as contradictory in the literature. For example, whereas Nasri and Zhang (2014) and Veneri (2010a) have illustrated that a more polycentric structure decreases trip distances and CO_2 emissions, Melo et al. (2012) and Lee and Lee (2014) have revealed an opposed association. Addressing the link between polycentricity and travel behavior externalities could therefore shed more light on the assumed advantages that come with polycentricity at the scale of metropolitan regions (see section 2.3 in chapter 2). Moreover, this research has important implications for spatial planning. The findings of this exploration also provide valuable insights into how the benefits of polycentricity can be realized in planning practice (see Figure 1.3 in the introduction to this thesis). More specifically, the estimated effects (e.g., elasticities or average marginal effects) of polycentricity on metropolitan performance could be provided to architects, planners, and policymakers alike in an evidence-informed manner that aims to establish a set of policy recommendations. In turn, the drafters of the 2010 Barcelona Metropolitan Territorial Plan may be interested in the ability of these policy recommendations to deliver on the Plan's objectives regarding, for example, reduced trip distances and times (see Generalitat de Catalunya, 2010).

This chapter aims to shed new light on the discussion of polycentricity and travel behavior externalities by answering the following specific research question (see section 2.5 in chapter 2): To what extent does polycentricity reduce trip distance, travel time and transportation-related CO_2 emissions, and how can its effects be realized in planning practice? Therefore, this chapter explores the extent to which Barcelona's polycentric metropolitan structure influences the presence of social and environmental externalities through individuals' travel behavior. This chapter will focus on three dimensions of that travel behavior—trip distance, travel time and transportation-related CO_2 emissions—that can be treated as negative externalities of travel when they result in costs. Additionally, this research translates the estimated effects of polycentricity into policy recommendations.

To adequately address the research question, this study applies an empirical framework that follows a conceptual model that more accurately describes both the composite (direct and indirect) and the causal relationships between polycentricity and travel behavior externalities. This conceptual model itself may contribute to the literature by providing a better understanding of the current discrepancies among the research findings on travel behavior externalities in the literature. Both the conceptual model and the empirical framework derived from it will incorporate the roles played by the built environment, trip makers' sociodemographic characteristics and trip makers' attitudes (following the theory of planned behavior and using the available data).

The empirical framework combines multilevel modeling and structural equation modeling into a single-model framework, which is denoted as multilevel structural equation modeling in the econometric literature. This method has not yet been applied to study the relationship between polycentricity and travel behavior. Multilevel modeling is designed to address the potentially biased estimation problems of using hierarchical data (e.g., individuals nested within municipalities) and thus, will enable this research to adequately control for the aggregation of determinants at different geographical levels. Structural equation modeling, in turn, enables the use of a large number of endogenous and exogenous variables to identify, disentangle, and simultaneously estimate complex causal relationships. Moreover, it enables this study to construct latent variables, which are factors that either are not observable or are not directly measurable but instead are a summarization of complex concepts (e.g., quality of life and job satisfaction). The use of structural equation modeling will therefore contribute to address the composite (direct and indirect) effects of polycentricity and the built environment on travel behavior externalities, the possible correlation between travel behavior externalities (e.g., trip distance and CO_2 emissions), and the importance of individuals' attitudes through the construction of latent variables (e.g., intention to use public transit).

Last (but not least important), this chapter covers two other research gaps. First, it increases the knowledge of how polycentricity has an impact on travel behavior externalities by considering different trip purposes—not just commuting, as most of the current studies in the literature have done. Second, it applies a more comprehensive and systematic empirical framework to attempt to unify the fragmented empirical research on the advantages of polycentricity and therefore, to achieve broader conclusions about its effects. To do so, this chapter builds on previous chapters. It again employs the centers identified in chapter 5. Additionally, it uses the conceptual framework proposed in chapter 2 and tested in chapter 7, which disentangles three distinct dimensions of how a polycentric spatial configuration can play a role in the development of agglomeration benefits in a metropolitan area: the size of centers, the (geographic) proximity to centers, and the aggregate size of centers through their integration.

The rest of the chapter is organized as follows. Section 8.2 reviews the literature on the link between polycentricity and travel behavior externalities. Section 8.3 discusses the reasons for discrepancies among the research findings on polycentricity and defines the main challenges involved in building a more comprehensive and systematic framework to examine its effects. Section 8.4 explains the conceptual model and underlying assumptions, and section 8.5 translates the model and assumptions into an empirical framework and presents the data and variables. Section 8.6 presents the findings from the analysis of travel behavior externalities. Finally, section 8.7 sets out the main conclusions and explains how the benefits of polycentricity can be realized in planning practice.

§ 8.2 The relationship between polycentricity and travel behavior externalities

There is a very rich body of literature on the link between the built environment, which is defined as the locational and morphological attributes of an urban area, and one or more externalities related to travel behavior, for instance, trip distance, travel time, CO_2 emissions, and the ecological footprint. In most of these studies, the impact of numerous built environment attributes in a neighborhood or a municipality such as density and land-use mix, along with others such as road density and block size, have been analyzed. So far, however, no consensus seems to have been reached about the effects of the built environment on travel behavior externalities; it is possible that this lack of consensus can be partially attributed to the fact that the spatial structure of the larger scale of metropolitan regions is often not considered. Indeed, few studies have considered that issue.

Scholars' first approach to addressing the relationship between metropolitan spatial structure and travel behavior externalities has been consideration of the role played by the central city in a metropolitan area. Several indicators such as 'to what extent are jobs concentrated in the central city', and 'to what extent do people want to reside in the central city' have been used to capture the effects of monocentricity on travel behavior externalities. In empirical analysis, however, 'distance from the place of residence of individuals to the central city' is the most frequently used variable.

In general, central cities provide a dense (compact) and mixed-land-use urban setting with a high concentration of jobs and various facilities served by good transportation links, thus increasing their accessibility from the rest of the metropolitan area. Scholars' first inference is that proximity to the central city increases the likelihood of individuals traveling shorter distances and either using public transit, walking, or cycling more. The second inference is that based on the previous inference, proximity to the central city also reduces travel's negative environmental impact. Most studies have identified this direct link between distance from the central city and trip distance (Naess, 2005; Nasri and Zhang, 2012; Watts, 2009), along with distance from the central city and environmental impact (Camagni et al., 2002; Muñiz et al., 2005, 2013; Travisi and Camagni, 2005; Travisi et al., 2010). In some respects, however, the empirical evidence suggesting that proximity to the central city diminishes trip time is ambiguous. For instance, congestion on radial transport axes towards the central city leads to lower travel speeds. Although Dubin (1991) and Levinson (1998) have revealed, for example, that greater distance from the central city is associated with longer travel times, Wang (2000) and Feng et al. (2013) have found that trips starting in suburban areas further from the central city may be of shorter duration.

Scholars' second approach to examining the link between metropolitan spatial structure and travel behavior externalities may be considered more accurate because this approach assumed that, today, metropolitan areas are no longer fully monocentric and thus, several centers coexist in a metropolitan area, forming a polycentric structure. Scholars have advanced three main hypotheses to empirically analyze the relationship between polycentricity and travel's negative externalities. These hypotheses are grounded on the theoretical framework of the 'co-location hypothesis'—i.e., the hypothesis that there is a periodic readjustment of the location of firms and households associated with positive effects on trip lengths and durations—and its consequences in terms of the use of transportation modes, as explained in chapter 7. First, the presence of several centers favors the proximity between work and non-work daily activities (e.g., shopping) and home and therefore, it increases the likelihood that individuals will perform their daily activities close to their place of residence. Second, polycentricity reduces the presence of excessive congestion effects (which are traditionally found when most trips develop radially to the central city) by spreading the concentration of population, jobs, amenities and facilities over multiple centers. This shift, in turn, influences individuals' travel times, which could be much lower because of higher travel speeds. Third, the agglomeration benefits in a polycentric metropolitan area—which, for example, imply a greater concentration of several types of jobs and amenities in centers—increase the relative competitiveness of public transport modes because more people will be encouraged to travel within, between and to centers to perform their daily activities. If these three hypotheses prove correct, then travel behaviors' negative environmental externalities (e.g., transportation-related CO_2 emissions) are likely to decrease.

However, empirical studies have not found conclusive answers regarding these hypotheses. On the one hand, Crane and Chatman (2003) and Nasri and Zhang (2014) have found that employment concentration in suburban zones and secondary centers, respectively, led to shorter trip distances compared to job concentration in the central city. In addition, Yang et al. (2012) and Gordon and Lee (2014) have illustrated similar effects of polycentricity in terms of travel times, when denser metropolitan areas and different proxies for job decentralization were considered. Furthermore, Veneri (2010a) has emphasized that metropolitan areas whose centers enjoy a greater spatial integration present travel behavior with a lower environmental impact. Likewise, Travisi et al. (2010) have found that polycentric urban systems lead to a decrease in transportation-related environmental impacts.

On the other hand, Schwanen et al. (2004) and Melo et al. (2012) have shown that more polycentric typologies of urban systems (e.g., 'decentralized' and 'exchange' systems) and a flatter rank-size distribution of employment in travel-to-work areas fostered longer trip distances. Similarly, Schwanen et al. (2003, 2004) and Susilo and Maat (2007) have shown that when individuals located in polycentric systems—namely, in 'decentralized' or 'exchange' daily urban systems in the Netherlands and in the Randstad polycentric urban region, respectively—they spent longer times traveling. In addition, Lee and Lee (2014) have recently found that the more polycentric a US metropolitan area, the higher its transportation-related CO_2 emissions. Thus, the debate about polycentricity and negative social and environmental travel behavior externalities remains unresolved.

§ 8.3 The reasons for discrepancies among research findings on polycentricity

This short review of the empirical research on the relationship between polycentricity and travel behavior externalities has illustrated that there is not yet a consensus about the role played by polycentricity. From this study's perspective, these discrepancies in outcomes can be partially explained by, on the one hand, conceptually and methodologically different approaches to the concept of polycentricity, and on the other hand, the application of different research methods.

Various approaches to polycentricity

Reconciling approaches to polycentricity

The first issue relates both to the conceptualization of polycentricity and to the examination of its effects based on two approaches that must be reconciled to obtain more conclusive answers about the link between polycentricity and travel behavior externalities. On the one hand, a body of literature has compared trip distance, travel time, and the environmental implications of travel in monocentric versus polycentric urban systems. This literature uses distinct analytical approaches to define a polycentric system. For instance, urban systems have been classified as either monocentric or polycentric based on their location (Susilo and Maat, 2007; Travisi et al., 2010)—for example, if they are located in a polycentric urban region such as the Randstad (Susilo and Maat, 2007)—the typology of an urban area or city (Dieleman et al., 2002; Levinson and Kumar, 1997; Naess, 2005; Schwanen et al., 2002), the functional typology of an urban system (Schwanen et al., 2001, 2002, 2003), and the distribution of cities in an urban system using the rank-size rule (Melo et al., 2012). However, these contributions are limited in that their definition of the urban systems might be too general to address the link between polycentricity and travel behavior externalities. As suggested in chapter 2 and comprehensively explained in chapter 7, it could be valuable to use a more precise method to identify the centers that shape a polycentric spatial configuration. Additionally, it was argued that that the three dimensions of a polycentric spatial configuration that play a role in the development of agglomeration benefits in a metropolitan area could be valuable for understanding and better explaining the link between polycentricity and travel behavior externalities. In other words, instead of classifying regions in a general manner, it is necessary to go into more spatial detail by examining how the size of centers, the proximity to centers and the interaction among centers affect travel behavior externalities.

That said, another approach starts with the identification of centers in metropolitan areas by examining either the spread of employment (Giuliano and Small, 1993; Gordon and Lee, 2014; Lee, 2006b; Lee and Lee, 2014; Nasri and Zhang, 2014; Shearmur, 2006; Wang, 2000; Yang et al., 2012) or the functional relationships among urban areas (Veneri, 2010a). The impact on travel behavior externalities is subsequently analyzed by considering some attributes of these identified centers, such as their spatial integration (Veneri, 2010a) and job concentration relative to the metropolitan area as a whole (Nasri and Zhang, 2014). Although this second approach focuses on a more appropriate geographical scale, it does not fully account for how centers have become united in a polycentric framework: i.e., either through decentralization or through incorporation-fusion. As explained in chapters 2 (see sections 2.2 and 2.3) and 5, this distinction is important because the dis(advantages) of polycentricity could depend on these two types of centers. Thus, my approach to studying the effects of polycentricity on travel behavior externalities will incorporate this dimension, thereby generally building on the second approach that starts from the identification of centers to the subsequent examination of their effects on the negative externalities of travel behavior. For that reason, I build on the method of identifying centers that is proposed in chapter 5.

The link between polycentricity and the built environment

A second issue relates to the how scholars have considered the link between polycentricity and the built environment in their analyses. Most studies in the research field of polycentricity and travel behavior externalities have not considered that polycentricity and some built environment attributes are interwoven and thus, polycentricity may have a composite (direct and indirect) impact on negative travel behavior externalities. Indeed, a city's built environment attributes, as argued in chapter 7, can be perceived as indicators of the presence of a wider range of (locally) agglomeration benefits in cities as their size increases. The composite effects of polycentricity, for example, could be related to the effects of proximity to centers. Proximity to centers (both central city and secondary centers) fosters higher employment densities in accordance with the New Urban Economics models (see chapter 5). Alternatively, the presence of several centers favors proximity between work and home (see chapter 7), which may mean that urban areas that are great distances from centers have lower jobs-housing ratios. In addition, these composite effects could be related to the agglomeration benefits that stem from the size of centers. This may imply that because, for example, centers (central city and secondary centers) are denser urban areas that have both a greater land-use mix and better access to various types of jobs and amenities than other types of cities because of the agglomeration benefits stemming from their larger city's size, the likelihood of their residents traveling shorter distances and times and generating lower CO_2 emissions can be higher when a trip starts or ends in them. Consequently, polycentricity could also have an indirect effect on negative travel behavior externalities through the mediation of some built environment attributes. Therefore, consideration of the interaction between polycentricity and the built environment may shed light on the causes of contradictory findings about the role played by polycentricity because it could avoid either underestimating or overestimating the total net effects of polycentricity on travel behavior externalities.

Various research methods and data

Various research methods may also explain the lack of conclusive answers in the debate about the relation between polycentricity and travel behavior externalities. Most scholars have used individuals as a basic unit of analysis while linking other variables at higher geographical levels (e.g., municipalities) to this first-level data for individuals to then apply standard econometric models to examine the relationship between polycentricity and trip distance (Dieleman et al., 2002; Schwanen et al., 2001), travel time (Schwanen et al., 2002; Susilo and Maat, 2007), or the negative environmental implications of travel (Muñiz et al., 2013). The use of econometric models with standard estimation techniques such as Ordinary Least Squares (hereafter, 'OLS') cannot take into account the fact that data have been aggregated at different geographical levels (e.g., individuals nested within municipalities), and thus, these standard models cannot control for within (e.g., between individuals) and between (e.g., across municipalities) grouping effects. This inaccurate treatment of microlevel variations leads to a reduced variation and standard errors in these standard models and therefore, may bias the estimation results in that the significance levels of the included determinants may be overestimated (Snijders and Bosker, 2012). In addition, the use of OLS regressions for hierarchical data violates the basic assumptions of independent measurements such as spatial autocorrelation (Raudenbush and Bryk, 2002). For instance, observations at the lowest geographical scale (e.g., individuals) clustered in the same higher geographical unit (e.g., municipality) share locational effects and are often more similar to each other than to individuals living in other municipalities, indicating that the process of decision-making (e.g., where to travel) is generally not random. The econometric literature has proposed addressing these estimation problems by estimating variations within and between groups by extending the random part of the models. However, this econometric proposal has barely been applied to polycentricity-travel behavior externalities studies. Only the studies of Schwanen et al. (2004), Nasri and Zhang (2012), and Zhang et al. (2012) have controlled for microlevel variation in the analysis of trip distance; Schwanen et al. (2003, 2004) and Lee and Lee (2014) have done so with regard to travel time and environmental externalities of travel, respectively.

A second issue that hinders the comparison of findings of across various studies is the use of different types of travel-related data. When examining the relationship between polycentricity and travel behavior externalities, many scholars have relied on aggregate data by taking a spatial unit such as travel-to-work areas, municipalities or metropolitan areas as the unit of analysis (Melo et al., 2012; Muñiz et al., 2005; Veneri, 2010a). Others, however, have employed hierarchical (or disaggregate) data at the individual-level (Naess, 2005; Nasri and Zhang, 2014; Schwanen et al., 2003, 2004). In this regard, contradictory findings may arise because the aggregate analysis does not control either for variations among individuals or for factors that affect their travel behavior (e.g., educational level attained, sex, household composition, age—see Burger et al., 2014b). Furthermore, aggregate data analysis suffer from the risk of ecological fallacy (see Ewing and Cervero, 2010; Schwanen et al., 2003, 2004). That is, such an analysis assumes spatial units are the subjects that act (e.g., the percentage of the population in a municipality that has a college degree and is above 25 years of age) on travel behavior, whereas in reality, the actors are individuals.

Another data-related issue is that many authors have focused their analyses on work-related travel, ignoring that travel patterns may be substantially different when non-work trips are considered, as the few studies that have considered them separately have shown (e.g., Cervero and Kockelman, 1997; Dieleman et al., 2002; Schwanen et al., 2002). For instance, Dieleman et al. (2002) have illustrated that although higher educational and income levels are often positively associated with longer travel distances for work- and leisure-trip purposes, they present a significant negative relationship when shopping trips are considered.

The challenges of examining the effects of polycentricity

The asserted discrepancies among the research findings on the interplay between negative travel behavior externalities and polycentricity call for further examination using an appropriate conceptual model to address the potential problems noted in the literature review. This conceptual model should consider the role played by polycentricity, how polycentricity is connected to certain built environment attributes and the influence exerted by other determinants that are often considered in the built environment-travel literature. In addition, this conceptual model should be translated into an empirical framework that allows not only the use of hierarchical data without biased estimates but also the identification and disentanglement of complex causal relationships. Furthermore, this empirical framework should be employed to estimate models for both work- and non-work-related travel.
The variables to measure polycentricity's effects on travel behavior externalities may be constructed based on the centers identified in chapter 5, which identifies centers by examining both the spread of employment and areas' functional relationships and thus, seems to represent a more comprehensive and systematic approach to defining polycentricity. Additionally, consideration of the three dimensions of a polycentric spatial configuration that play a role in the development of agglomeration benefits in a metropolitan area, as proposed in chapter 2, could contribute to build a more comprehensive and systematic empirical framework to examine the effects of polycentricity. The point is that (1) the size of centers, (2) the (geographic) proximity to centers, and (3) the aggregate size of centers through their integration are significant to their performance in a metropolitan area (see chapters 2 and 7). The translation of these dimensions of a polycentric metropolitan structure into an empirical framework requires the use of the aforementioned conceptual model to identify, for example, the (composite) effects of being located in or oriented towards centers and of being located close to these centers. Therefore, it can be argued that the previously discussed issues appear to be a sound basis for empirical research that answers the research question phrased in this chapter: To what extent does polycentricity reduce trip distance, travel time and transportation-related CO_2 emissions, and how can its effects be realized in planning practice? The next section builds the conceptual model and its related hypotheses.

§ 8.4 Conceptual model and hypotheses

This section builds a conceptual model that identifies the relationships between factors related to polycentricity, the built environment attributes of urban areas, the sociodemographic characteristics of trip makers, the theory of planned behavior, and travel behavior externalities. The structure of the conceptual model, which is the basis of the model framework explained in section 8.5, is shown in Figure 8.1. The assumed relationships among the determinants and the expected hypotheses that underpin the key associations tested in this study are explained below in a set of subsections. These subsections first explain the relationships that appear at the top of Figure 8.1 and then progress to the bottom.

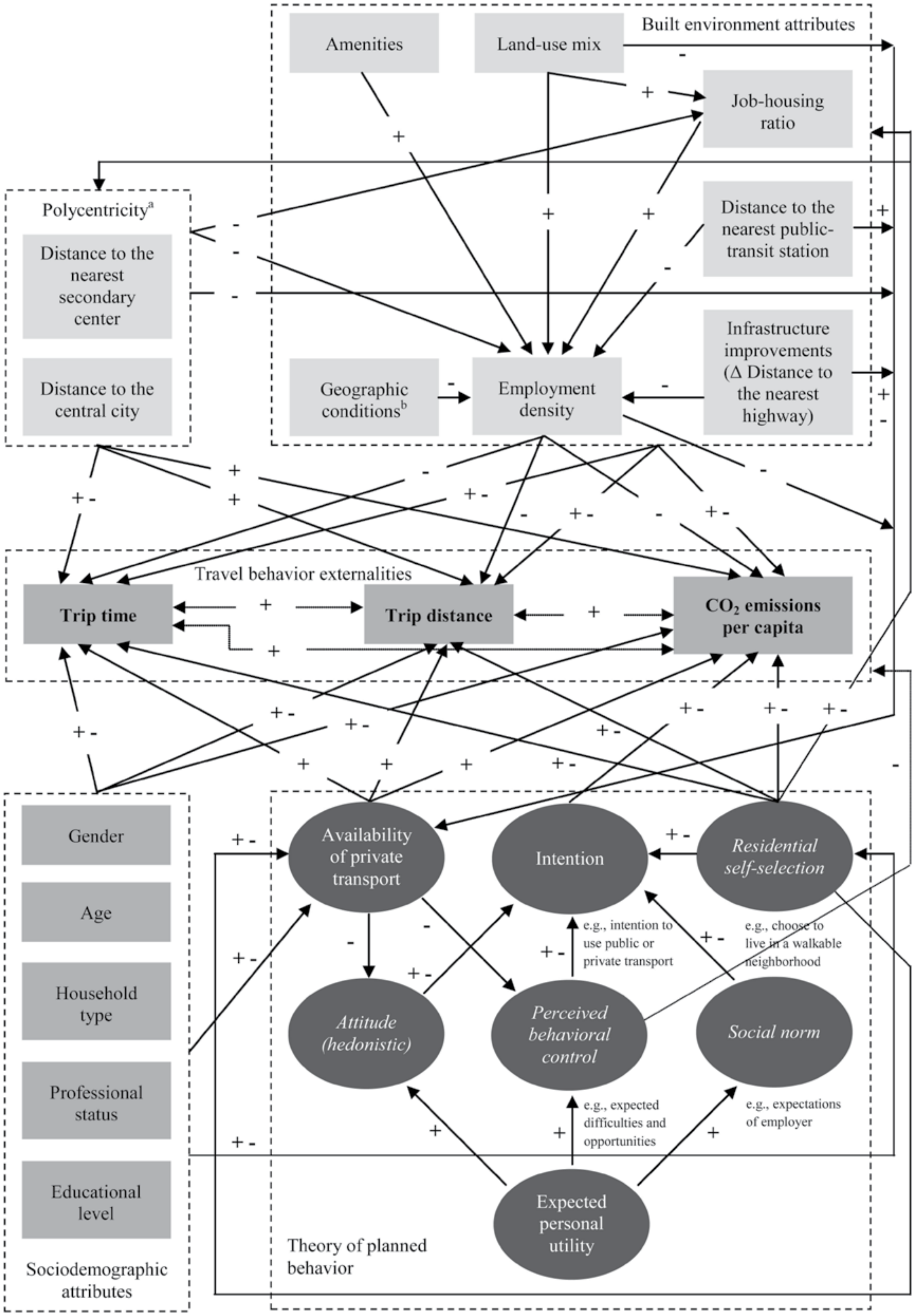

FIGURE 8.1 Conceptual model for assessing travel behavior externalities and key relationships (with expected hypothesis) among main determinants

a. In this conceptual model, the effects of polycentricity by means of the effects of (geographic) proximity to centers are represented. However, the effects of polycentricity based on the effects of the size of centers (e.g., trip origin in a center and trip destination in a center) also could have been displayed. In this case, the expected hypothesis for these alternative polycentricity effects could be different, and they are explained in the manuscript.
b. Geographic conditions in the case study of the Barcelona metropolitan region are represented by municipalities' distance to the coast.

The effects of polycentricity and the built environment

First, it is assumed that polycentricity and differences in the built environment directly influence trip time, trip distance and transportation-related CO_2 emissions per capita. The effects of polycentricity proxied by the distance to the central city and the distance to the nearest secondary center are expected to be positive on trip distance and CO_2 emissions, as explained in section 8.2. In other words, the greater the distance from a center, the longer the trip distance and the higher the CO_2 emissions. Because of congestion effects, however, the effects of proximity to centers are hypothesized to be either positive or negative with respect to travel times (Anas et al., 1998).

In addition, the effects of the size of centers (central city and secondary centers) at both trip origin and trip destination could exert a positive influence, thus mitigating travel behavior externalities. The hypothesis advanced in this study (not shown in Figure 8.1) is that centers hold the types of urban attributes stemming from the agglomeration benefits created by their larger city size (e.g., greater presence of several types of high-order amenities and jobs), which allows residents a high level of access to their daily activities through short trip distances, short trip times, the use of a wider range of sustainable transportation modes. Consequently, when a trip begins in a center and to a lesser extent ends in one—because centers may attract people from more distant locations seeking to access their agglomeration benefits (e.g., jobs, amenities, etc.)—the probability that the trip results in greater negative travel behavior externalities is lower than when the trip begins in another type of place (e.g., a peripheral area).

The impact of the built environment is also assumed as either positive or negative. The functional diversification of an urban area, as expressed in its land-use mix and jobs-housing ratio, can reduce travel behavior externalities. Because facilities are distributed relatively densely in urban areas with a high level of land-use mix, individuals in these areas are expected both to travel shorter distances and to need less time to access them (Cervero, 1996a; Frank and Pivo, 1994). Similarly, a more balanced distribution between an urban area's economic and residential functions brings home and work closer to each other and thus, residents in such areas tend to experience reduced trip distances and durations (Giuliano and Small, 1993). Because of the decreased distance between jobs and households, functional diversification can also mitigate the level of CO_2 emissions or other pollutants (Cirilli and Veneri, 2010a). Similar reasoning applies to the presence of urban amenities. It can be assumed that the higher the presence of urban amenities in an urban area (e.g., hospitals, theatres, sports stadiums, restaurants, etc.), the lower the travel behavior externalities because individuals are expected to travel shorter distances and need less time to reach their destinations.

However, the role played by other built environment characteristics can be more ambiguous. Whereas higher densities are expected to be associated with shorter trip distances (Cervero and Murakami, 2010; Elldér, 2014) and CO_2 emissions (Aguilera and Voisin, 2014; Lee and Lee, 2014; Veneri, 2010a) because of their greater concentration of houses and jobs, the influence of dense working or residential areas on travel times can be negative. This may be caused by residents' greater exposure to traffic congestion in dense areas (Glaeser and Kahn, 2004), which tends to be even more severe in metropolitan areas where trips are oriented radially toward the central city (Anas et al., 1998). Similarly, infrastructure improvements could also exert either a positive or a negative impact on travel behavior externalities. For instance, it can be assumed that infrastructure improvements, which enhance the accessibility of urban areas over time, may reduce travel behavior externalities for work-related travel. The plausible explanation could be that as infrastructure improvements increase the level of accessibility, both the length and the duration of trips may decrease because residents not only have the ability to access more jobs within a given travel time and distance but also enjoy a wider range of transport modes (Cervero and Murakami, 2010; Levinson, 1998). However, infrastructure improvements could also lead to longer trip distances, longer trip times and higher transportation-related CO_2 emissions for non-work-related travel. An explanation could be that some urban functions (e.g., shopping areas) that were too distant before infrastructure improvement might have become potential destinations.

Second, polycentricity is also expected to influence travel behavior externalities indirectly, through certain built environment attributes such as employment density and job-housing ratios, as noted in section 8.3. Furthermore, other built environment attributes such as amenities, distance to the nearest public-transit station, and infrastructure improvements may have an indirect effect on travel behavior externalities by mediating employment density. In addition, it can be assumed that land-use mix determines the job-housing ratio because the more mixed an urban area, the more balanced the distribution of its economic and residential functions. Finally, it is important to note that proximity to centers—greater job densities or mixed land-use, for example—decreases an individual's propensity to be a car owner or have a drivers' license (Naess, 2005). Consequently, it is also assumed that polycentricity and the built environment may influence travel behavior externalities indirectly, by mediating individuals' access to private transport.

The theory of planned behavior

The greater availability of private transport (e.g., car or motorcycle ownership) directly and positively influences the time and length of trips and their related CO_2 emissions (Modarres, 2011; Nasri and Zhang, 2012; Watts, 2009). In addition, private transport availability, which can be treated as a latent variable because its measurement depends on more than one variable to consider all of its dimensions (e.g., car and motorcycle), could indirectly affect travel behavior externalities. However, these indirect effects are more complex than the others because they are often mediated through other latent variables related to the theory of planned behavior, which requires this study to make its best effort (given the available data) to consider self-selection effects (i.e., individuals' travel- and residential-related attitudes) within the conceptual model.

The theory of planned behavior was developed by Ajzen (Ajzen, 1991, 2011) to understand how individuals form intentions to perform behaviors. Although the theory of planned behavior was originally formulated to conduct research in the field of psychology and health (e.g., organizational behavior and human decision processes), it has been widely used in travel studies to explore the link between individuals' travel-related attitudes and their willingness to use certain transportation modes (see Bothe, 2010).

Ideally, a study aimed at examining individuals' attitude towards travel behavior should consider, as Bothe (2010) has noted, three beliefs identified by the theory of planned behavior that guide individuals' behavior. First, some beliefs about a travel behavior are created by individuals, who associate that behavior with certain attributes. These 'behavioral beliefs' form individuals' (hedonistic) attitudes toward behavior, which can be defined as the individuals' favorable or unfavorable evaluation of performing their (intended) travel behavior (Chowdhury and Ceder, 2013): e.g., the consequences of using public transport (expenditure for the ticket) and the importance of that choice (Peng et al., 2014). Second, some beliefs are created by either approval or disapproval about performing a travel behavior. These 'normative beliefs' form the basis of social norms, which can be defined as individuals' perceptions of a social obligation to perform (or not perform) an action (Chowdhury and Ceder, 2013): e.g., my friends consider using the train to be "…" (subjective norms) or my family will use the train (descriptive norms) (Peng et al., 2014). Third, there are beliefs about individuals' perceived barriers to performing an action. These 'control beliefs' form the perceived behavioral control, which can be defined as the individuals' perception of ease or difficulty in performing the (intended) travel behavior (Chowdhury and Ceder, 2013): e.g., it will make feel troubled to choose a particular travel mode (Peng et al., 2014).

Individuals' expected personal utility is assumed to have some type of influence on (hedonistic) attitude, perceived behavioral control, and social norms—e.g., if individuals expect a transportation mode to be reliable (expected personal utility), the more this mode fulfills that expectation, the higher the probability that there could be a change in individuals' perceived difficulties in taking their (intended) trip using that transportation mode (perceived behavioral control). These three aforementioned factors, in turn, either positively or negatively influence the development of a behavioral intention to use a specific transportation mode (e.g., public transport).

The general hypothesis here is that the more favorable the (hedonistic) attitude, the social norms, and the perceived behavioral control related to one particular transportation mode—e.g., public transport—, the stronger the intention of individuals to perform the travel behavior in question, and the weaker the probability of performing other types of travel behavior (see, e.g., Peng et al., 2014). Consequently, the effects of individuals' intentions on higher CO_2 emissions are expected to be either positive (i.e., with the intention to use private transport) or negative (i.e., with the intention to use public transport). Furthermore, given a sufficient degree of actual perceived behavioral control over their travel behavior, people are assumed to carry out their intentions, provided the opportunity arises and the resources (e.g., time and money) are available.

Private transport availability may therefore indirectly influence travel behavior externalities by mediating individuals' (hedonistic) attitudes or perceived behavioral control, along with their intention to use a particular transportation mode. For example, the higher the private transport availability, the more likely individuals are either to negatively evaluate the expected consequences of traveling by public transport (e.g., expenditure for a ticket) or to perceive more barriers to traveling by public transport.

Moreover, the theory of planned behavior allows the consideration of residential self-selection effects when a study contains the ideal data. This type of self-selection effect can be defined as individuals' residential-related attitudes at the time that they choose their residential location within a particular built environment that will suit their travel-related attitudes (Cao et al., 2007, 2009). These attitudes towards residential areas influence the residential location's built environment attributes through the evaluation of alternative residential locations when an individual searches for a new home (Bothe, 2010). For instance, people may choose to live in a dense neighborhood with a high presence of urban amenities because they like to walk to those amenities. Therefore, it can also be assumed that residential self-selection determines (at least to some degree) individuals' private transport availability and their behavior intention to use certain transportation modes. Consequently, it is expected that residential self-selection influences travel behavior externalities not only directly but also indirectly, through built environment attributes, private transport availability, and individuals' intentions.

The sociodemographic attributes of trip makers

Another crucially important relationship in this conceptual model involves the differences in individuals' sociodemographic characteristics, which determine trip time, trip distance and transportation-related CO_2 emissions per capita. These attributes' direct influences on travel externalities can be either positive or negative. For instance, being a female is generally found to be a strong predictor for shorter trip distances, shorter travel times, and lower CO_2 emissions (Naess, 2005; Susilo and Maat, 2007), whereas a high educational level can foster greater negative travel behavior externalities either because such people more often can afford private transport or because cities with jobs that require a high level of education are distributed in a manner that is more spatially uneven (Elldér, 2014; Veneri, 2010a).

Moreover, individuals' specific characteristics may indirectly influence travel behavior externalities through the aforementioned latent variables of private transport availability and residential self-selection. For example, the likelihood of choosing to live in urban areas with low residential density (residential-related attitudes) may vary according to an individual's socioeconomic profile.

Travel behavior externalities

Finally, the conceptual model expects a positive correlation (interdependence) not only between trip distance and CO_2 emissions but also between travel time and trip distance and between travel time and CO_2 emissions. In this regard, the theoretical background has noted, for example, that distance traveled (Cervero and Murakami, 2010) and travel time (Cirilli and Veneri, 2010b, 2010c; Travisi et al., 2010) could be somewhat representative of the environmental impact of travel. The next section explains the research approach that enables the application of this conceptual model.

§ 8.5 Research approach: data, variables and empirical framework

Data and variables

To achieve its research goal, this study draws on mobility data derived from the Daily Mobility Survey (*Enquesta de Mobilitat Quotidiana* (hereafter, 'EMQ')). The EMQ, which was elaborated by the Metropolitan Transportation Authority (*Autoritat del Transport Metropolità* (hereafter, 'ATM')) of Barcelona, was designed to collect comprehensive information about the attributes of all of an individual's trips (e.g., trip purposes, transportation modes) for one week. Since 1996, ATM has conducted EMQs during each 5-year period. This research selected the 2001 EMQ because the 2011 edition is not available; the 2006 edition was ruled out for reasons explained in chapter 7 (see footnote 26).

The survey questionnaire of the 2001 EMQ was randomly distributed to residents of all of the 164 municipalities in the Barcelona metropolitan region, and 402 distinct survey zones were defined. This survey questionnaire was completed by 30,740 people, who provided information about approximately 342,975 trips; the trip purposes (12 different categories) and modes of transport (16 distinct modes) were also reported. This allows the aggregation of individuals' trips into work and non-work trips, and into private transportation, public transportation, and walking-bicycling, if the latter option would be convenient. Furthermore, the detailed information in the 2001 EMQ enables the consideration of a variety of sociodemographic characteristics for these 30,740 individuals and the subjective opinion (attitudes) on different travel-related topics for 12,427 individuals. This study aims to focus on the travel behavior of individuals who can travel relatively independently. For this reason, individuals aged 16 years and older were selected.

The trip maker's sociodemographic attributes and travel-related attitudes at the individual-level (level-1) in the 2001 EMQ dataset, combined with other variables related to the built environment and polycentricity measured at the municipal-level (level-2), define this study's research design as examining the causes for travel behavior externalities, as summarized in Figure 8.2. In this analysis, individual-specific characteristics are operationalized first by the gender (male or female) of the individuals. Second, this work considers their age, their professional status, and their educational level. Third, the individuals' household type is considered by examining the total number of household members, the number of children (below 4 years of age), and the number of teenagers (between 4 and 16 years of age).

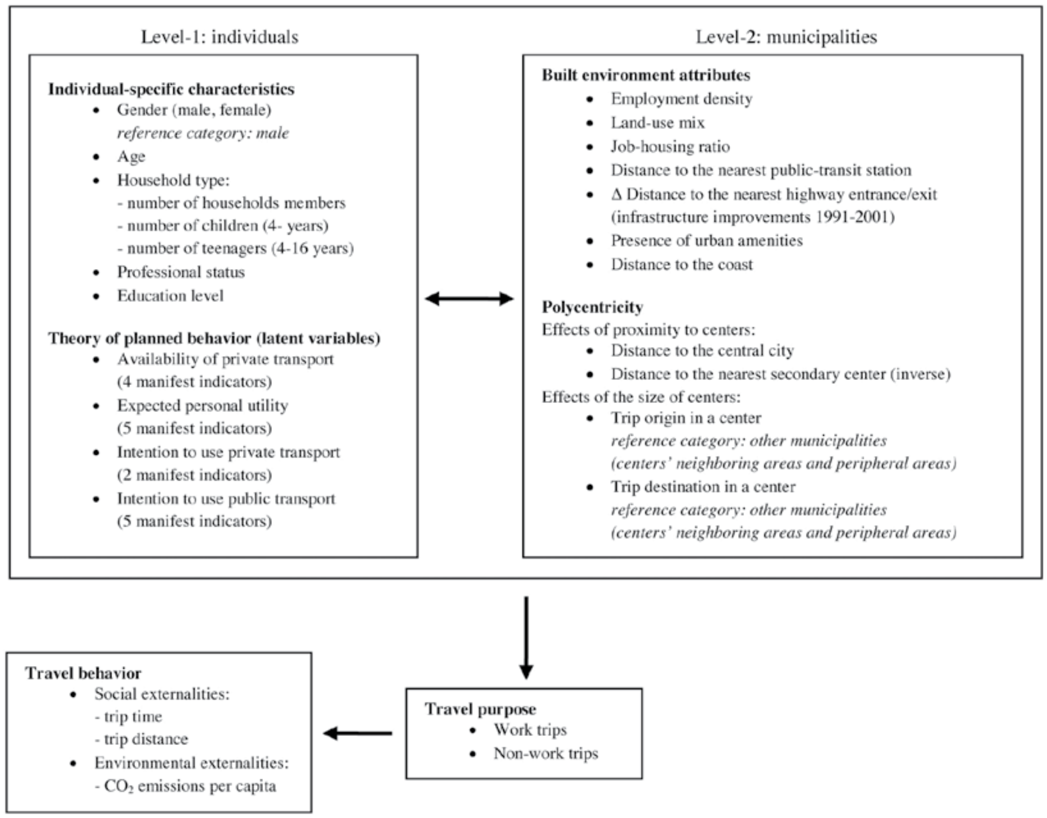

FIGURE 8.2 Research design of the travel behavior externalities analysis

The latent variables related to the theory of planned behavior are constructed using two or more manifest indicators for each latent variable. Unfortunately, because of the EMQ's data limitations[32], the latent variables of (hedonistic) attitude, perceived behavioral control, social norms, and residential self-selection considered in the conceptual model (see Figure 8.1) could not be included in this analysis. Thus, four latent variables have been considered: the availability of private transport to individuals, expected personal utility, the intention to use private transport, and the intention to use public transport. These variables are built as follows. Private transport availability is built using 4 manifest variables (owning a car or a motorcycle, and having a drivers' license or a motorcycle license), expected personal utility is built using 5 items (evaluation of the importance of comfort, safety, price/cost, speed, and frequency of transportation), intention to use private transport is built using 2 indicators (global assessment of car and motorcycle), and intention to use public transport is built using 5 items (global assessment of bus, urban bus, metro, FGC train, and RENFE train). In this regard, the manifest variables for private transport availability are dummy variables (yes or no), whereas the manifest indicators for the other latent variables come from the individuals' assessment of a set of

32 The subsample of the 2001 EMQ referred to individuals' opinions about transportation. It did not accurately ask about all of the factors implicated by the theory of planned behavior, nor did it accurately ask about individuals' residential-related attitudes. Thus, it does not permit the construction of manifest indicators for these latent variables.

attributes regarding transportation in general and an evaluation related to specific transportation modes using a continuous scale of values (0: very unimportant to 10: very important).

The built environment attributes of the respondents are based on defining the locational and morphological attributes noted by the conceptual model. These built environment variables, which have been constructed on the municipal scale (level-2) using the currently available datasets for the Barcelona metropolitan region, are as follows: employment density, land-use mix, job-housing ratio, distance to the nearest public-transit (train and metro) station, increment of the distance to the nearest highway entrance/exit between 1991 and 2001, presence of urban amenities, and distance to the coast. The variable increment of the distance to the nearest highway represents the effects of infrastructure improvements on travel behavior externalities. Note that both the infrastructure improvements and the public-transit stations can be observed in Appendix 5.1 to chapter 5.

The data employed to determine these variables come from the following datasets. First, employment data come from the 2001 census data supplied by the *Instituto Nacional de Estadística* (hereafter, 'INE'). Second, the land-use dataset is provided by the Department of Territorial Policy and Public Works (hereafter, 'DPTOP') of the Catalan government; that dataset was used in the 2010 Barcelona Metropolitan Territorial Plan. These data define 7 land-use categories: urban-industrial, high-density urban-residential, low-density urban-residential, urban-residential in historical city centers, urban-services, system-urban facilities, and system-urban services. With this data, this chapter calculates the employment density and the land-use mix measured using the entropy index proposed by Frank and Pivo (1994). Third, housing data are also from the 2001 census data supplied by INE. Using this dataset and the employment dataset, the job-housing ratio is calculated. Fourth, data on highway (entrances and exits) and railway networks with the location of the public-transit stations are provided by DPTOP. The calculation of the distances (in kilometers) to the nearest highway and public-transit station is conducted using Geographic Information System (hereafter, 'GIS') software. Fifth, urban amenities data are obtained from the *Institut d'Estadística de Catalunya* (hereafter, 'IDESCAT'). These data are measured for 2000, 2001, and 2003 depending on the type of amenity (educational, leisure, cultural and sport, health, and social well-being) under consideration. To calculate the presence of amenities, a normalized score index ranging from 0 to 100 has been calculated. Sixth, the data required to calculate the variable distance to the coast come from the matrix of minimum distance by road between municipalities in Catalonia provided by DPTOP for 2001. From this, the distance from each municipality in the Barcelona metropolitan region to the nearest coastal municipality has been calculated using GIS software.

The polycentricity variables are based on the centers (central city and 12 secondary centers) identified in 2001 using the identification method proposed in chapter 5. Moreover, following chapter 2, chapter 7, and the explanations of section 8.3, this study considers the distinct dimensions of a polycentric spatial configuration that play a role in the development of agglomeration benefits in a metropolitan area. This approach to polycentricity could allow this study to define an empirical framework to examine its effects that is more comprehensive and systematic than other previous research about travel behavior, therefore arriving at broader conclusions. Taking the aforementioned centers, this research therefore defines the following polycentricity variables to consider two main effects. First, this study considers the attenuation with distance of the agglomeration benefits stemming from the size of centers by defining two variables. These are the distance to the central city (Barcelona) and the inverse of the distance to the nearest secondary center[33]. These two variables have widely used by scholars to empirically assess the polycentric

33 The inverse form of the distance to the nearest secondary center is defined to mitigate the multicollinearity between this variable and distance to the central city. As explained in chapter 5, this decision has been proposed by most of the studies that have assessed the existence of a polycentric model in metropolitan areas (e.g., McMillen and Smith, 2003).

model in metropolitan areas (see chapter 5) and essentially, they measure the effects of (geographic) proximity to centers (central city and secondary centers).

Second, this research considers the agglomeration benefits stemming from the size of centers by defining two dummy variables. These variables measure the extent to which the effects of the size of centers differ from (e.g., are more important than) the effects of the size of other types of cities. Whereas the first dummy variable refers to the trip origin (trip origin in a center is coded as 1, otherwise 0), the second dummy variable examines the effects of the size of centers at the destination (trip destination in a center is coded as 1, otherwise 0). Moreover, these two dummy variables could proxy for the impact of the built environment attributes. It can be argued that when an individual makes a trip in a center, he or she is being influenced by the agglomeration benefits stemming from the size of this center (e.g., greater accessibility to several types of jobs and amenities) and therefore, one can also expect that effects of built environment attributes to vary widely among distinct types of places in a metropolitan area (e.g., centers and non-center areas). The key point is that the presence of (positive) built environment attributes (and thus, the magnitude of their effects) depends on city size because those attributes can be understood as indicators of agglomeration benefits. The data required to calculate these variables come from the matrix of minimum road distance (in kilometers) between municipalities in Catalonia provided by DPTOP for 2001. From this, the distance of each municipality in the Barcelona metropolitan region to the central city and to the nearest secondary center is calculated using GIS software.

Finally, this study defines negative travel behavior externalities based on the available datasets for the Barcelona metropolitan region as follows. Whereas those negative externalities associated with social costs to travelers have been examined by considering trip distance and trip time, the negative externalities associated with environmental costs to society have been approximated by considering both the CO_2 emissions from transportation modes and distance traveled. These three travel behavior externalities are calculated as follows. First, the distance traveled and time spent by each trip maker from the trip origin (municipality) to the trip destination (municipality) have been computed based on the road distance and road time between the municipalities. The data required to quantify both of the variables come from the matrixes of the minimum road distance (in kilometers) and the minimum road time (in minutes) between municipalities in Catalonia provided by DPTOP for 2001. Second, transportation-related CO_2 emissions per capita have been calculated by using an estimate provided by Amici della Terra (2005:25-26) (which provides the CO_2 equivalent weight generated per kilometer traveled for several transportation modes), the previous distance matrix dataset supplied by DPTOP, and each individual's transportation mode according to the 2001 EMQ data[34].

Empirical framework

Initial model framework: multilevel modeling

The discrepancies among the research findings highlighted in the literature review of section 8.2 have shown that this research should use multilevel modeling to disentangle within-grouping effects (between individuals) and between-grouping effects (across locations) when individuals' travel behavior is examined. The few studies that apply multilevel modeling (e.g., Elldér, 2014; Schwanen et al., 2003, 2004) have defined a random intercept model instead of using other, more complex

34 After adapting the estimates provided by Amici della Terra (2005) for the 16 transportation modes defined by the 2001 EMQ, the number of CO_2-equivalent kilograms for each 1 km origin-destination trip is estimated as follows: walking=0, bus=72, metro=21.30, train (FGC)=35, train (RENFE)=35, bus (company)=31, bus (school)=31, coach=72, taxi=105, car (driver)=105, car (passenger)=0, motorcycle (driver)=80, motorcycle (passenger)=0, bicycle=0, van/truck=158, others=0, private transportation=103, and public transportation=33.

multilevel models. These models imply the extension of the standard OLS models through its random part to allow for variation around the intercept. The development of a random intercept model specification building on a standard OLS model can be expressed as follows:

$$Y_{ij} = \alpha + \boldsymbol{\beta_1 X_{1ij}} + \boldsymbol{\beta_2 X_{2j}} + \varepsilon_{ij}$$

EQUATION 8.1

where (Y_{ij}) is one of the travel behavior externalities considered in this study (e.g., trip time) for individual (i) of municipality (j), ($\mathbf{X_{1ij}}$) is a vector of explanatory variables at the individual-level, ($\mathbf{X_{2j}}$) is a vector of covariates at the locational-level (municipality), and ($\boldsymbol{\varepsilon}_{ij}$) is the error term. This OLS model may be unrealistic because it assumes that the trip times of individuals living in the same municipality are uncorrelated given the independent variables. To address this potential problem, the econometric literature (e.g., Snijders and Bosker, 2012) has proposed to split the total error term ($\boldsymbol{\varepsilon}_{ij}$) into two error components: (u_{ij}), which is unique to each individual; and (u_j), which is shared between residents of the same municipality. Substituting for ($\boldsymbol{\varepsilon}_{ij}$) into equation 8.1, the random intercept model is obtained:

$$Y_{ij} = (\alpha + u_j) + \boldsymbol{\beta_1 X_{1ij}} + \boldsymbol{\beta_2 X_{2j}} + u_{ij}$$

EQUATION 8.2

This model can be interpreted as a regression model with a municipal-specific intercept (α+u_j) or with an added level-2 residual (u_j). The random intercept (u_j) can be viewed as a latent variable that is not estimated along with the fixed part of the model defined by the vector parameters ($\boldsymbol{\beta_1}$) and ($\boldsymbol{\beta_2}$), but whose variance (ψ) is estimated together with the variance (θ) of the error term at level-1 (u_{ij}). These level-2 residuals constitute a municipal-specific error component that remains constant across the response (e.g., trip distance), whereas the level-1 residual (u_{ij}) is an individual-specific error component that differs from that of individuals (i) and municipalities (j). Moreover, the level-2 residuals are uncorrelated over municipalities, the level-1 residuals are uncorrelated over municipalities and individuals, and the two error components are uncorrelated with each other. The variance across municipalities (ψ) and the variance within municipalities (θ) define the total variance of multilevel regressions. These values enable an estimation of the proportion of the total variance (ψ+θ) that is caused by variation across municipalities (level-2 units) by dividing the municipal variance (θ) by the total variance. This proportion of the total variance is denoted either as the unconditional intraclass correlation in a model that does not include any independent variables or as the conditional intraclass correlation in a model that includes covariates. Intraclass correlation values are key estimates for revealing the significance of level-2 units to the response variable (e.g., trip time) because they estimate how much the total variability is explained by municipalities—for instance, whether all variance stems from the municipal-level, which would entail that individuals within a single municipality experience identical trip times.

For multilevel regressions, no straightforward goodness-of-fit statistics exist. As a possible surrogate for R^2 of the standard OLS models, Snijders and Bosker (2012) propose a Pseudo R^2 by estimating the proportional reduction in the estimated total variance, comparing the only-intercept model (without covariates) with the model of interest. Another possibility, as Raudenbush and Bryk (2002) suggest, is to consider the proportional reduction in each of the variance components separately. This results in two Pseudo R^2, one for each level. In this regard, it is important to note that these Pseudo R^2 indicate the extent to which the responses (e.g., trip time) can be predicted from the independent variables and not how appropriate the model is for the data. However, the use of these random-intercept multilevel regressions cannot also disentangle and estimate the composite effects between determinants on travel behavior externalities according to the key hypothesis advanced by the conceptual model. In this regard, the following subsection presents a model framework that has the ability to consider and estimate these composite (direct and indirect) relationships between determinants.

Suitable model framework for the conceptual model: structural equation modeling

Structural equation modeling is employed to examine the assumed relationships of the conceptual model depicted by Figure 8.1. It is a modeling technique that manages a large number of endogenous variables, exogenous variables, and latent (unobserved) variables specified as a linear combination of observed variables (manifest indicators) to identify and simultaneously estimate complex causal interrelationships. Structural equation modeling not only has been widely applied in the field of psychology, education, and public health but also has been used in travel studies to relate activity demand and travel, or built environment and household characteristics, to travel behavior (Golob, 2003). In this regard, the use of structural equation modeling is noted to be the best option to fulfill all of the methodological requirements for analyzing the influence of travel and residential-related attitudes on travel behavior (Mokhtarian and Cao, 2008).

An important distinction in structural equation modeling compared to other econometric techniques is that it enables the model to break down and estimate the causal effects into direct and indirect effects. The total effects are the sum of the direct and indirect effects, where the latter represent the sum of all of the other effects mediated by at least one other variable. Another key feature is that structural equation modeling is a confirmatory rather than an exploratory analysis because it is suited to test a theory with its related hypothesis about causal relations between variables, as represented in a model specification.

The model specification of a structural equation model is generally composed of a measurement model that includes underlying manifest (observed) indicators to measure latent variables, as in the confirmatory factor analysis, along with a structural model that specifies the causal effects of the exogenous variables on the endogenous variables and the causal effects between endogenous variables. The measurement model can be expressed as follows:

$$\boldsymbol{Y}_i = \boldsymbol{\tau} + \boldsymbol{\Lambda}\boldsymbol{\eta}_i + \boldsymbol{K}\boldsymbol{X}_i + \boldsymbol{\varepsilon}_i$$

EQUATION 8.3

where (i) denotes cases (e.g., individuals or municipalities), ($\mathbf{Y}_i$) is a px1 column vector of observed variables, ($\boldsymbol{\tau}$) is a px1 column vector of intercepts, ($\boldsymbol{\varepsilon}_i$) is a px1 column vector of error terms, ($\boldsymbol{\Lambda}$) is a pxm matrix in which m is the number of latent variables, ($\boldsymbol{\eta}_i$) is an mx1 vector of latent variables, and $\mathbf{K}$ is a pxq matrix of coefficients for the q exogenous variables in ($\mathbf{X}_i$). The structural model can be formulated in this manner:

$$\boldsymbol{\eta}_i = \boldsymbol{\alpha} + \boldsymbol{B}\boldsymbol{\eta}_i + \boldsymbol{\Gamma}\boldsymbol{X}_i + \boldsymbol{\zeta}_i$$

EQUATION 8.4

where ($\boldsymbol{\alpha}$) is an mx1 vector of intercepts, ($\mathbf{B}$) is an mxm matrix of coefficients for the ($\boldsymbol{\eta}_i$) vector of all latent variables, ($\boldsymbol{\Gamma}$) is an mxq matrix of coefficients for exogenous variables, and ($\boldsymbol{\zeta}_i$) is a mx1 vector of errors terms. The residuals in ($\boldsymbol{\varepsilon}_i$) and ($\boldsymbol{\zeta}_i$) are assumed to be normally distributed with zero means and with covariance matrices $\boldsymbol{\Theta}$ and $\boldsymbol{\Psi}$, respectively.

Many overall goodness-of-fit statistics have been developed for evaluating a structural equation model and quantifying how well one model does versus another model. The most common test used in structural equation modeling is the chi-square statistic, which measures the minimum difference between the observed and the estimated variance-covariance matrix (Garson, 2012). The aim is to attain a non-significant model chi-square (>0.05 level) because a significant chi-square indicates that the estimated covariance matrix is significantly different from the observed one. Nevertheless, the chi-square statistic increases substantially with larger sample sizes (>150-200 observations) and larger correlations in the model. In these cases, it may be very difficult to find a model that cannot be rejected and thus, other statistics have been introduced by scholars (see Garson 2012). These alternative indexes include the Comparative Fit Index (hereafter, 'CFI'), the Tucker-Lewis Index (hereafter, 'TLI'), the Root Mean Square Error of Approximation (hereafter, 'RMSEA'), and the Standardized Root Mean Square Residual (hereafter, 'SRMR').

The CFI compares the extent to which our model is better than a null model that assumes there is no relationship between covariates. It ranges from 0 to 1 and values greater than 0.90 indicate a reasonably good fit. The TLI is similar to the CFI and controls for sample size; however, the TLI penalizes for model complexity. The larger the correlations in the model, the higher the TLI values. The TLI also ranges from 0 to 1 and values greater than 0.90 indicate a good fit. The RMSEA takes the amount of error for each degree of freedom into account. This is one of the fit indexes that is less affected by sample size and that penalizes the model for unnecessary added complexity. It is recommended that RMSEA be less than 0.05 for a good fit and less than 0.08 for an acceptable fit. The SRMR quantifies how close the model comes to reproducing each correlation where values of less than 0.08 indicate a good fit. Moreover, an equation for the goodness-of-fit statistic can be obtained to assess each endogenous variable of the structural equation model. This is the R^2 statistic that measures the proportion of the explained variance of the endogenous variables by the covariates. However, conventional structural equation models are only suitable when the data structure is not hierarchical. If the data structure is hierarchical, a synthesis of multilevel modeling and structural equation modeling is required to obtain a valid statistical inference because failing to adequately control for microlevel variation may lead to false inferences, as noted in section 8.3 and the previous explanations of multilevel modeling. This synthesis of multilevel modeling and structural equation modeling, which will become the preferred model framework of this study to apply the conceptual model, is presented in the following subsection.

The applied model framework: multilevel structural equation modeling

The synthesis of multilevel modeling with structural equation modeling in a single model framework, which the econometric literature denotes as multilevel structural equation modeling, would lead to a combination of the strengths of multilevel modeling with structural equation modeling. More specifically, the primary advantage of a multilevel structural equation model over multilevel models is that the former obtains a reduced bias estimation and an increased statistical power when hierarchical data are used (Preacher et al., 2010, 2011). Two main approaches to extending structural equation models for multilevel settings have appeared in the literature, each with both advantages and limits.

On the one hand, the most common approach specifies a multilevel structural equation model using a structural equation modeling framework as a starting point, which results in a separate within-cluster and between-cluster structural model together with a measurement model (e.g., Muthén, 1994). This approach has been used by Lee and Lee (2014), who are the first to employ multilevel structural equation modeling to analyze the link between polycentricity and travel behavior externalities.

On the other hand, a second approach specifies a multilevel structural equation model using a multilevel modeling framework as a starting point, which leads to a unifying model framework denoted as Generalized Linear Latent and Mixed Models (hereafter, 'GLLAMMs'), which consists of a measurement model that includes latent variables in addition to random intercepts and coefficients along with a structural model that incorporates latent and observed variables that vary at different levels (Rabe-Hesketh et al., 2004, 2007).

Among the six main limitations of the traditional within-between approach over the GLLAMM approach detected by Rabe-Hesketh et al. (2004:169), perhaps the most important is that this traditional multilevel structural equation modeling implementation does not allow the model to consider the cross-level effects from latent or observed variables at a higher-level on latent variables at a lower-level. Nevertheless, the main limitation of GLLAMMs is that the goodness-of-fit measures mentioned above, which have been developed to assess a structural equation model, are not available and thus, only those goodness-of-fit statistics related to multilevel modeling can be obtained (intraclass correlation and Pseudo R^2 for each equation).

Consequently, this study specifies multilevel structural equation models using the GLLAMM framework: as the conceptual model has shown (see Figure 8.1), the links between variables at different levels are the focus of this research. In this regard, this study is the first application of multilevel structural equation modeling within the GLLAMM framework to the study of the link between polycentricity and travel behavior externalities. Based on Rabe-Hesketh et al. (2007), the measurement model of the GLLAMM framework for continuous responses, which is a generalized linear model specified via a linear predictor, a link function, and a conditional distribution of the response variable, is formulated as follows:

$$\upsilon = \boldsymbol{\beta}'\boldsymbol{X} + \sum_{l=2}^{L}\sum_{m=1}^{M_l}\eta_m^{(l)}\boldsymbol{Z}_m^{(l)\prime}\boldsymbol{\lambda}_m^{(l)}$$

EQUATION 8.5

where the indices for units at different levels have been omitted to simplify the notation, response variable (y) given (**X**), (**z**), and (**η**) is linked to the linear predictor at some level (υ) via link function $g(E[y|\boldsymbol{x},\boldsymbol{z},\boldsymbol{\eta}]) = \upsilon$, and the conditional distribution of the response variable for continuous responses is $y = \upsilon + \varepsilon$. The elements of vector (**X**) denotes explanatory variables related to coefficients (**β**), (L) represents the levels of nesting and (M_l) represents the latent variables at level l>1. The (m^{th}) latent variable at level (l), $\eta^{(l)}_m$, is multiplied by a vector of explanatory variables $\mathbf{Z}^{(l)\prime}_m$ and a vector of its corresponding coefficients $\boldsymbol{\lambda}^{(l)}_m$ (factor loadings), where the first element of $\boldsymbol{\lambda}^{(l)}_m$ is typically set to 1 ($\boldsymbol{\lambda}^{(l)}_{m1}$=1).

As Rabe-Hesketh et al. (2007:10) note, this measurement model allows the incorporation of latent variables at different levels, random intercepts and coefficients, or both. For example, in this chapter, $\eta^{(l)}_m$ can take the form of an individual-level latent variable (e.g., intention to use private transport) of individual (j) in municipality (k) expressed as $\eta^{(2)}_{jk}$ with a vector of factors $\mathbf{Z}^{(2)}_{1k}$, where two indicators (i) are defined (k_{i1}=car, k_{i2}=motorcycle), and a vector of its related factor loadings $\boldsymbol{\lambda}^{(2)}_1$ is expressed as [1 $\boldsymbol{\lambda}^{(2)}_2$]. Moreover, $\eta^{(l)}_m$ can take the form of a municipal-level random intercept for each travel behavior externality considered in this research (e.g., trip distance), expressed as $\eta^{(3)}_k$, with a vector of explanatory variables $\mathbf{Z}^{(3)}_{2k}$ and a vector of its corresponding factor loadings $\boldsymbol{\lambda}^{(3)}_2$ set to 1 in this case.

The structural model of the GLLAMM framework resembles the structural model for single-level structural equation models (see equation 8.4), with one relevant difference: it not only allows latent variables at the lower-level to be regressed on other latent variables (at the same- or higher-levels) and observed variables but also permits the specification of random intercepts and random coefficients. Consequently, the vector of the latent variables (**η**) and observed variables (**X**) of this structural model includes variables that may vary at different levels (e.g., $\eta^{(2)}_{jk}$, X_{1jk}, X_{2k}). Moreover, the vector of error terms ($\boldsymbol{\zeta}$) may incorporate one error term ($\zeta^{(2)}_{jk}$) that differs from lower-level (j) and higher-level (k) units and another error term, which is a random intercept ($\zeta^{(3)}_{k}$) that represents a higher-level latent variable ($\zeta^{(3)}_{k} = \eta^{(3)}_{k}$). This inclusion will enable this study to evaluate all of the key relationships between the variables established in the conceptual model depicted in Figure 8.1. For instance, lower-level latent variables (e.g., $\eta^{(2)}_{jk}$: private transport availability) are to be regressed on same-level latent variables (e.g., $\eta^{(2)}_{jk}$: expected personal utility) and observed variables either at the same-level (e.g., X_{1jk}: age) or at higher-levels (X_{2k}: distance to the central city).

This study develops the implementation of multilevel structural equation modeling as follows. First, before adding any observable and latent variables to establish the direct and indirect relationships defined in the conceptual model (see Figure 8.1), this research estimates an intercept-only multilevel structural equation model by using maximum likelihood with adaptive Gaussian quadrature as a integration method to evaluate and maximize the marginal log-likelihood following Rabe-Hesketh et al. (2004). When the estimates for the random terms in this multilevel structural equation model (variance at level-1 and level-2 for trip time, trip distance and CO_2 emissions) for work and non-work travel are statistically significantly larger than zero, the expectation that individuals clustered in the same municipality share locational effects is corroborated. The estimates of this multilevel structural equation model confirm this expectation (see the following section of results). The primary advantage of using adaptive Gaussian quadrature to fit multilevel structural equation models over other alternative numerical integration methods (e.g., penalized quasi-likelihood) is that it works well for continuous responses and its accuracy can be examined by comparing estimations with different number of quadrature points. In the application of adaptive Gaussian quadrature integration, 8 quadrature points have appeared sufficient for an accurate estimate.

Second, this study adds not only observed variables at level-1 and level-2 but also latent variables to this intercept-only multilevel structural equation model (see Figure 8.2) and again estimates a multilevel structural equation model using maximum likelihood with adaptive Gaussian quadrature (8 quadrature points). In this regard, two multilevel structural equation model specifications have been defined. One considers the polycentricity variables in relation to the effects of proximity to centers (model 1-P1), and the other considers those variables in relation to the effects of the size of centers (model 2-P2).

Third, the model fit of the multilevel structural equation models for work and non-work travel has been assessed by calculating the previously explained goodness-of-fit measures related to multilevel modeling. These measures include not only the un- and conditional intraclass correlation but also the overall, the level-1, and the level-2 Pseudo R^2 for the equations of trip time, trip distance, and CO_2 emissions. Moreover, the model fit statistics provided when a structural equation model is estimated have also been used to evaluate the estimated multilevel structural equation models. It can be assumed that there would have been little difference between these model fit measures and those derived from a multilevel structural equation modeling estimation if the GLLAMM framework had not had the limitation of failing to provide overall model fit statistics.

§ 8.6 Polycentricity and the externalities of travel behavior

Model fit of the estimated multilevel structural equation models

The detailed path diagrams of the estimated multilevel structural equation models for work-related travel regarding to models 1-P1 and 2-P2 are shown in Figures 8.3 and 8.4, respectively, whereas the path diagrams of the estimated multilevel structural equation models with respect to these two model specifications and non-work-related travel are presented in Figures 8.5 and 8.6, respectively. These four path diagrams display the observed variables at level-1 (individual-level) or level-2 (municipal-level) in rectangles, the latent variables at level-1 in an oval shape, and the latent variables or random intercepts at level-2 in a double-ringed oval shape. Endogenous (dependent) and exogenous (independent) variables have been connected by arrows specifying the direction of the effect and the estimated (standardized) coefficient (elasticity) with its significance level. Elasticities enable a clearer interpretation of these estimated effects and provide policymakers with useful information to establish planning policy recommendations (see Ewing and Cervero, 2010) and thus, their estimation could contribute to shedding more light on how the benefits of polycentricity can be realized in planning practice. The goodness-of-fit statistics are reported in the top-left corners of Figures 8.3, 8.4, 8.5, and 8.6, whereas the statistics related to the intercept-only and the random intercept multilevel structural equation model are displayed at the center of those figures.

The statistics of the intercept-only multilevel structural equation model indicate that multilevel modeling is appropriate for both work and non-work travel and for both model 1-P1 and model 2-P2 specifications. The estimated variance at level-1 and level-2 is statistically significant above a 99% confidence level. In addition, the unconditional intraclass correlation, which measures the proportion of the total variance explained by hierarchical grouping when explanatory variables are not included, ranges from 0.211 to 0.306 for work travel and from 0.165 to 0.318 for non-work travel. The goodness-of-fit statistics related to the random intercept multilevel structural equation models have also revealed that multilevel modeling is necessary. The conditional intraclass correlation, which considers all covariates added to the model, ranges from 0.105 (Figure 8.4) to 0.185 (Figure 8.3) for work travel, and from 0.051 (Figure 8.6) to 0.191 (Figure 8.5) for non-work travel. Consequently, this indicates that individuals nested within the same municipality spend similar trip distances and times, causing quite comparable CO_2 emissions. The Pseudo R^2 statistics are reasonably good, suggesting that in this study, travel behavior externalities can be predicted by covariates. For instance, level-2 Pseudo R^2 values range from 0.382 (Figure 8.3) to 0.600 (Figure 8.4) for work travel and from 0.329 (Figure 8.5) to 0.783 (Figure 8.6) for non-work travel.

However, these overall, level-1, and level-2 Pseudo R^2 statistics do not indicate how appropriate the model is for the data. In this regard, the goodness-of-fit measures obtained by estimating the multilevel structural equation models for work and non-work travel without including the three random intercepts have shown that all of the models have an overall good or reasonable fit. The four models hold goodness-of-fit indexes that exceed or satisfy the range of values determined by each index (CFI, TLI, RMSEA, and SRMR) that indicates a reasonable fit. Only the chi-square is not satisfied, but this is because of the larger sample size and correlations of the models as explained previously; accordingly, this does not represent a reason to readjust the models.

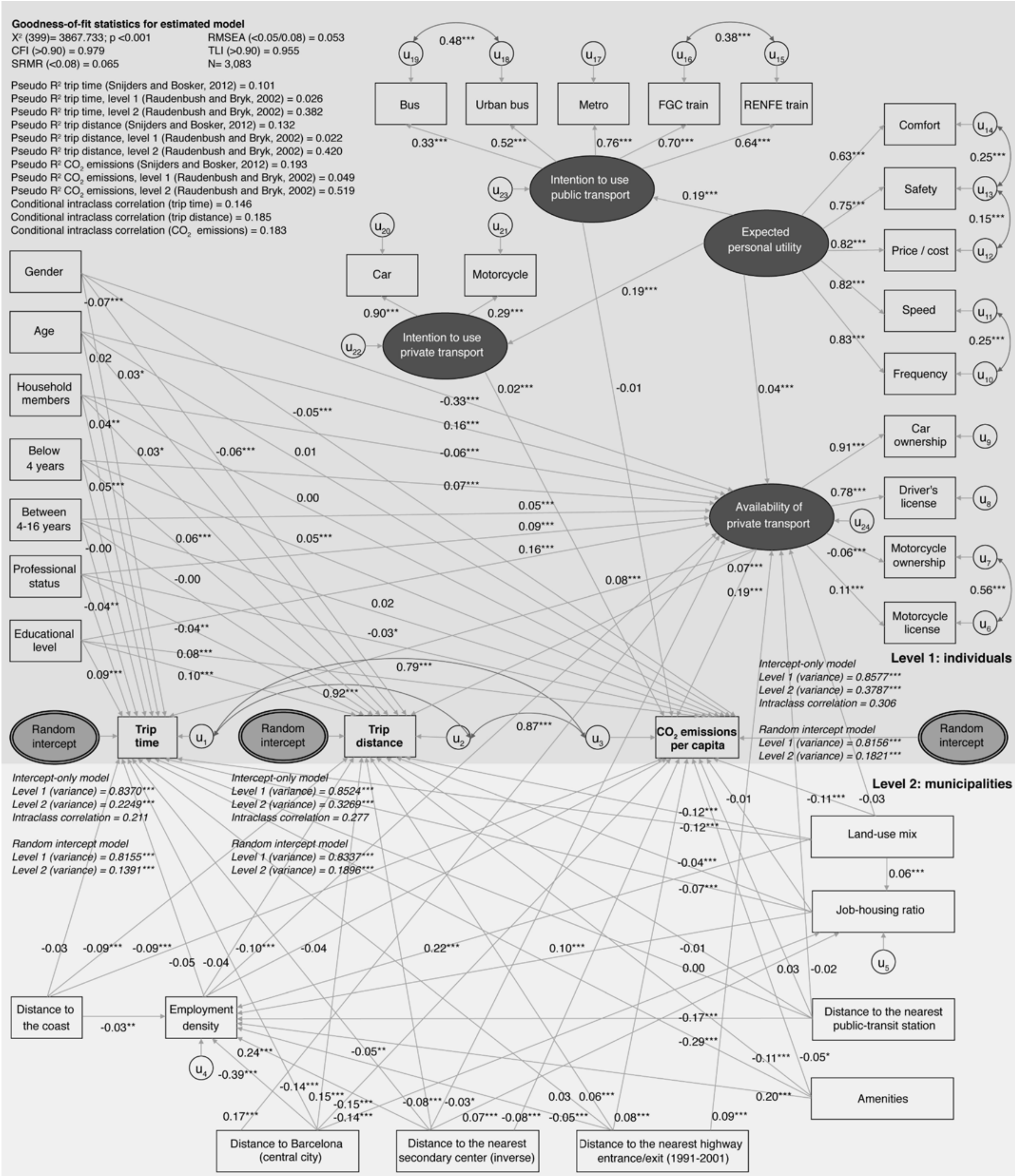

FIGURE 8.3 Multilevel structural equation model: results for model 1-P1 (effects of proximity to centers) and work-related travel

****, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1), respectively.*
Note(s): the results display standardized coefficients. CFI: Comparative fit index; TLI: Tucker-Lewis index; RMSEA: Root mean square error of approximation, and SRMR: Standard root mean square residual. In this multilevel structural equation model, a random intercept (a random effect) has been included at the individual level: one for each travel behavior externality under examination (trip time, trip distance, and CO_2 emissions per capita). Thus, a double-ringed random intercept represents a latent variable at the municipal level, meaning that it is constant within municipalities and varies across them.

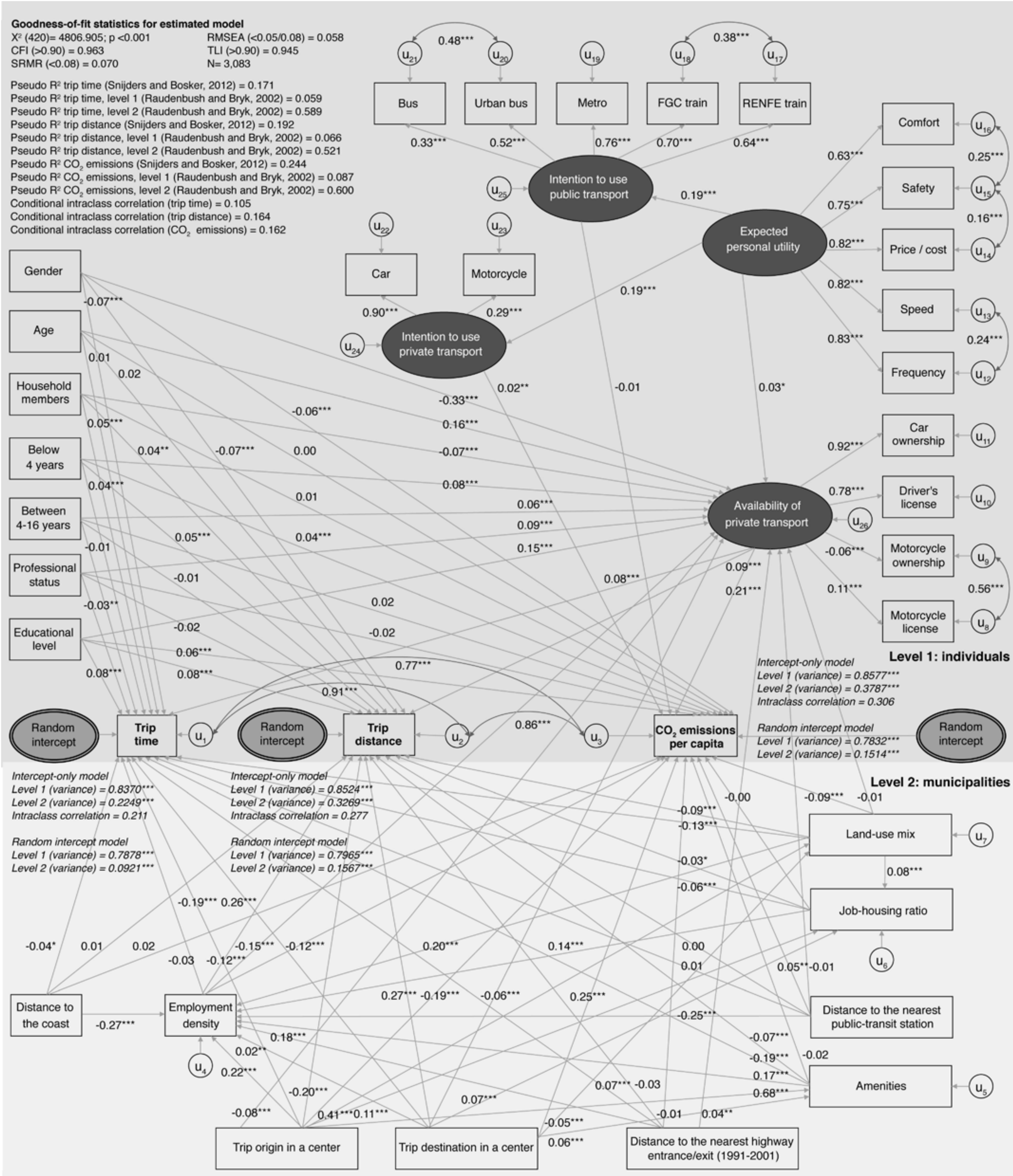

FIGURE 8.4 Multilevel structural equation model: results for model 2-P2 (effects of the size of centers) and work-related travel

****, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1), respectively.*
Note(s): the results display standardized coefficients. CFI: Comparative fit index; TLI: Tucker-Lewis index; RMSEA: Root mean square error of approximation, and SRMR: Standard root mean square residual. In this multilevel structural equation model, a random intercept (a random effect) has been included at the individual level: one for each travel behavior externality under examination (trip time, trip distance, and CO_2 emissions per capita). Thus, a double-ringed random intercept represents a latent variable at the municipal level, meaning that it is constant within municipalities and varies across them.

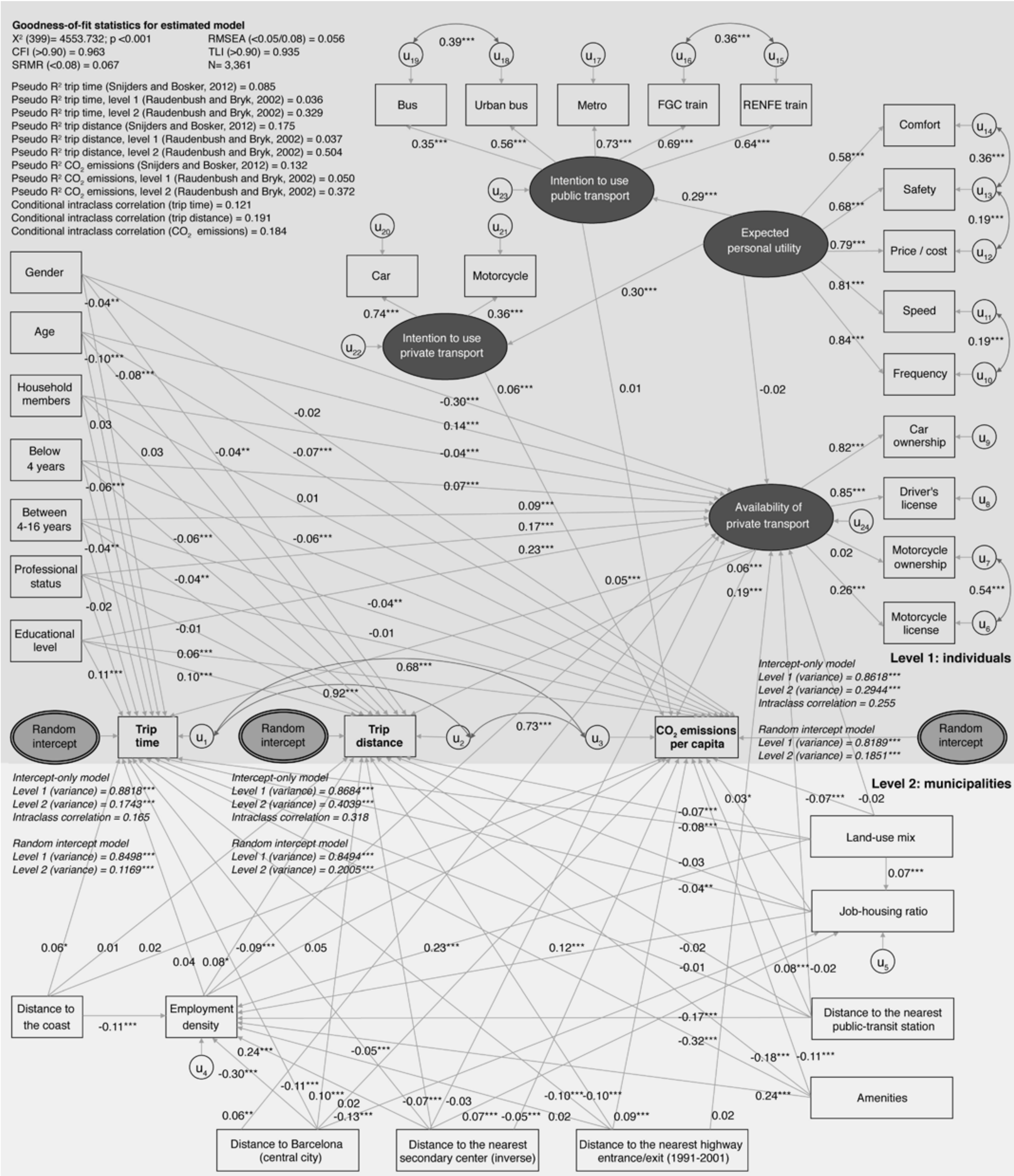

FIGURE 8.5 Multilevel structural equation model: results for model 1-P1 (effects of proximity to centers) and non-work-related travel

****, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1), respectively.*
Note(s): the results display standardized coefficients. CFI: Comparative fit index; TLI: Tucker-Lewis index; RMSEA: Root mean square error of approximation, and SRMR: Standard root mean square residual. In this multilevel structural equation model, a random intercept (a random effect) has been included at the individual level: one for each travel behavior externality under examination (trip time, trip distance, and CO_2 emissions per capita). Thus, a double-ringed random intercept represents a latent variable at the municipal level, meaning that it is constant within municipalities and varies across them.

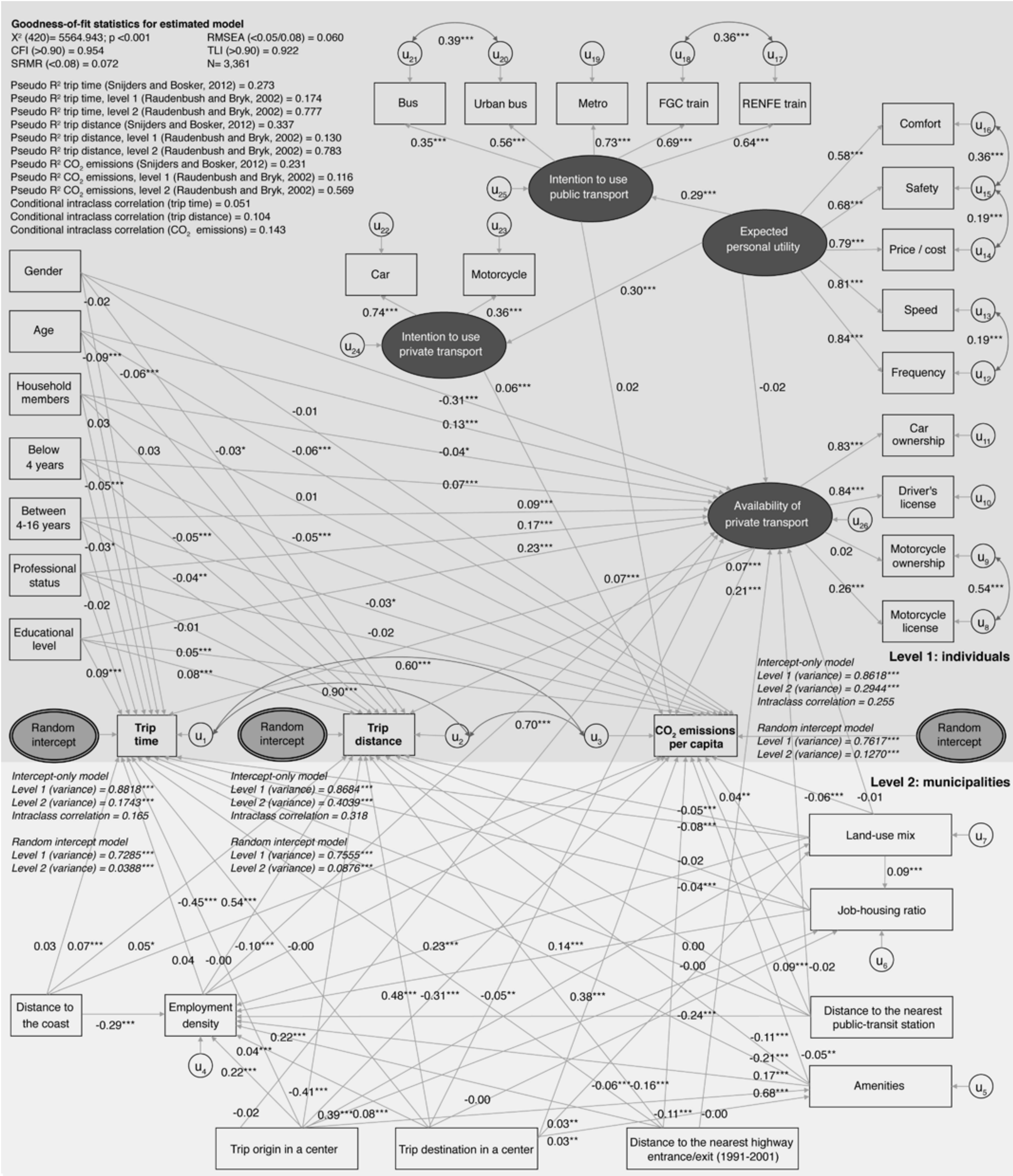

FIGURE 8.6 Multilevel structural equation model: results for model 2-P2 (effects of the size of centers) and non-work-related travel

****, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1), respectively.*
Note(s): the results display standardized coefficients. CFI: Comparative fit index; TLI: Tucker-Lewis index; RMSEA: Root mean square error of approximation, and SRMR: Standard root mean square residual. In this multilevel structural equation model, a random intercept (a random effect) has been included at the individual level: one for each travel behavior externality under examination (trip time, trip distance, and CO_2 emissions per capita). Thus, a double-ringed random intercept represents a latent variable at the municipal level, meaning that it is constant within municipalities and varies across them.

The determinants' total effects on travel behavior externalities

Work-related travel

The direct, indirect, and total effects of the determinants on trip time, trip distance, and CO_2 emissions per capita for work-related travel, considering both the effects of proximity to centers (model 1-P1) and the effects of the size of centers (model 2-P2), are shown in Table 8.1. Most of the total effects exerted by explanatory variables at level-1 are statistically significant for all of the travel behavior externalities considered in this study. In particular, being male, being older, having small children, having a high educational level, and having greater private transport availability increases trip distance, trip time, and CO_2 emissions. These results are consistent with previous studies that have also found similar effects regarding age (e.g., Schwanen et al., 2003; Zhang et al., 2012), gender (e.g., Elldér, 2014; Wang, 2013), household type (e.g., Bento et al., 2005), educational level (e.g., Feng et al., 2013; Susilo and Maat, 2007), and ownership of private transport (e.g., Nasri and Zhang, 2012; Schwanen et al., 2004). The largest of these estimated total effects of individual-level determinants is associated with individuals' private transport availability in terms of CO_2 emissions. Doubling the availability of private transport is associated with an increase in CO_2 emissions of nearly 19.50% (model 1-P1) or 21.00% (model 2-P2), all else being equal. With respect to trip time and distance, educational level in model 1-P1 and gender in model 2-P2 appear to be the strongest predictors, with a total elasticity of approximately 0.10 in absolute terms.

The magnitude of the estimated effects of built environment attributes and polycentricity are at least as large as the individual-level determinants after controlling for individuals' sociodemographic characteristics and travel-related attitudes. Moreover, most of these effects not only present the expected sign in accordance with the conceptual model depicted in Figure 8.1 but are also statistically significant. In terms of the net elasticities of the built environment variables on travel behavior externalities, the following remarks can be made when we include the effects of proximity to centers (model 1-P1). The total effect of urban amenities is quite high, yielding elasticity estimates of -0.3015, -0.1166, and -0.0602 for trip time, trip distance, and CO_2 emissions, respectively. This indicates that doubling a municipality's concentration of urban amenities will lead to a 30.15% reduction in trip time, a 11.66% decrease in trip distance, and a 6.02% reduction in CO_2 emissions, with all other variables being constant. Similarly, the impact of a greater land-use mix and to a lesser extent, a higher job-housing ratio, induce individuals to travel shorter distances, spend less time, and produce lower transportation-related CO_2 emissions. In addition, it is important to note that a 10% reduction in the distance to the nearest highway entrance/exit (i.e., a 10% increase in infrastructure improvements) is associated with 0.71% less trip distance and 1.03% lower CO_2 emissions. In contrast, proximity to the nearest public-transit station (train and metro) is only positively and statistically significant related to decreased negative travel behavior externalities in terms of CO_2 emissions. Furthermore, the estimated density effects do not exert any influence on individuals' trip distance and trip time, whereas the significant net elasticity of density on CO_2 emissions is quite moderate (-0.0624) compared to other elasticities found in previous studies (e.g., Cervero and Murakami, 2010; Lee and Lee, 2014).

These unexpected density elasticities merit further discussion. First, highly dense areas' greater exposure to traffic congestion may explain the negative (but not statistically significant) effect on trip time. Second, the effect of density may vary according to the type of city in which the trip starts. Although the effect of density on travel behavior externalities could be higher for trips starting in centers, they are either modest or not significant in the more peripheral areas outside centers.

Model 2-P2 incorporates variables indicating where a trip begins and ends, shedding more light on the effects of density and the other built environment attributes shown in model 1-P1. This shows that doubling the employment density in a municipality will lead to a considerable reduction in trip distance (13.04%) and CO_2 emissions (14.71%), along with a slight decrease in trip time (3.81%). Moreover, when a trip starts in a center, the degree of employment density in that type of place is 24.59% [exp(0.2198) - 1] higher than when this trip starts in other types of places (i.e., centers' neighboring areas and peripheral areas). Likewise, when a trip ends in a center, the level of employment density in that type of place is 2.44% [exp(0.0240) - 1] higher (see Figure 8.4). This higher level of employment density when a trip starts or ends in a center, in turn, implies the higher impact of reducing travel behavior externalities. For instance, the effect of a trip starting in a center on trip distance mediated through employment density is -0.0258 (0.2198 x -0.1176). This shows that because of centers' higher density levels, the trip distance of a center's residents is 2.62% [exp(0.0258) - 1] lower than the trip distance of a non-center area's residents. Therefore, these findings corroborates that the effect of density varies according to the type of city and may reinforce the previous explanations of why density had an unexpected effect in model 1-P1.

In addition, the total effect of urban amenities has become more moderate when controlling for the location where the trip starts and ends. Now, doubling the concentration of urban amenities in a municipality will lead to a 19.62% decrease in trip time and a 9.43% reduction in trip distance, but it has no significant total effect on CO_2 emissions. The total effects exerted by infrastructure improvements have become more ambiguous in this model specification. Although an increase in infrastructure improvements was significantly associated with smaller trip distance and lower CO_2 emissions in model 1-P1, an increase in infrastructure improvements (e.g., 10% reduction in the distance to the nearest highway entrance/exit) is now significantly related to shorter trip times (e.g., 0.63% less because of the aforementioned 10% reduction) and longer trip distances (e.g., 0.50% longer because of the that reduction).

Regarding the effects of polycentricity in terms of benefits associated with being proximate to centers (model 1-P1), the net elasticity of distance to the central city and the inverse of the distance to the nearest secondary center indicate that in general, the greater the proximity of residential areas to centers, the lower the negative travel behavior externalities. A 10% decrease in distance to the nearest secondary center will lead to a 0.68% reduction in trip time, a 0.96% shorter trip distance, and a 0.99% decrease in CO_2 emissions. The effects of proximity to the central city are even stronger with respect to trip distance (1.87% for a 10% decrease) and CO_2 emissions (2.11% for a 10% decrease). However, the further an individual lives from the central city, the lower his or her likelihood of making longer-duration trips: e.g., a 10% increase in distance results in a 0.91% decrease in trip time. This may confirm that congestion along the radial transportation axis towards the central city continues to play an important role in Barcelona; it is a major cause of the decreased travel speed and increased trip times experienced by individuals traveling to the central city.

ENDOGENOUS VARIABLES	WORK-RELATED TRAVEL					
	MODEL 1-P1 (FIGURE 8.3)			MODEL 2-P2 (FIGURE 8.4)		
	DIRECT EFFECTS[A]	INDIRECT EFFECTS[A]	TOTAL EFFECTS[A]	DIRECT EFFECTS[A]	INDIRECT EFFECTS[A]	TOTAL EFFECTS[A]
Trip time < determinants						
Level 1 Individual-specific characteristics						
Gender	-0.0680***	-0.0256***	-0.0936***	-0.0733***	-0.0281***	-0.1014***
Age	0.0170	0.0122***	0.0292*	0.0091	0.0135***	0.0225
nº of household members	0.0410**	-0.0048***	0.0362*	0.0516***	-0.0055**	0.0460**
nº of children (4- years)	0.0494***	0.0056***	0.0550***	0.0433***	0.0063***	0.0496***
nº of teenagers (4-16 years)	-0.0008	0.0040**	0.0032	-0.0092	0.0047**	-0.0044
Professional status	-0.0404**	0.0070***	-0.0334**	-0.0328**	0.0077***	-0.0251
Educational level	0.0859***	0.0123***	0.0982***	0.0821***	0.0129***	0.0950***
Level 1 Theory of planned behavior						
Availability of private transport	0.0763***	(no path)	0.0763***	0.0844***	(no path)	0.0844***
Expected personal utility	(no path)	0.0029*	0.0029*	(no path)	0.0026	0.0026
Level 2 Built environment attributes						
Employment density	-0.0509	-0.0076***	-0.0584	-0.0256	-0.0124***	-0.0381***
Land-use mix	-0.1164***	-0.0198**	-0.1362***	-0.1315***	-0.0142***	-0.1457***
Job-housing ratio	-0.0733***	-0.0059***	-0.0791***	-0.0617***	-0.0053***	-0.0670***
Distance to the nearest public-transit station	0.0089	0.0088	0.0177	0.0079	0.0102	0.0180
Δ Distance to the nearest highway entrance/exit (infrastructure improvements 1991-2001)	0.0313	0.0095***	0.0408	0.0658***	-0.0031	0.0627***
Presence of urban amenities	-0.2895***	-0.0120	-0.3015***	-0.1897***	-0.0065***	-0.1962***
Distance to the coast	-0.0254	0.0020	-0.0234	-0.0420	0.0104	-0.0316
Level 2 Polycentricity						
Distance to Barcelona (central city)	-0.1376***	0.0468***	-0.0908***			
Distance to the nearest secondary center (inverse)	-0.0461**	-0.0223**	-0.0684***			
Trip origin in a center				-0.1852***	-0.2158***	-0.4010***
Trip destination in a center				0.2619***	-0.0208***	0.2411***
Trip distance < determinants						
Level 1 Individual-specific characteristics						
Gender	-0.0613***	-0.0246***	-0.0859***	-0.0663***	-0.0291***	-0.0955***
Age	0.0293*	0.0117***	0.0410**	0.0175	0.0139***	0.0314*
nº of household members	0.0329*	-0.0046**	0.0283	0.0404**	-0.0057**	0.0347*
nº of children (4- years)	0.0555***	0.0054***	0.0609***	0.0478***	0.0065***	0.0543***
nº of teenagers (4-16 years)	-0.0021	0.0038**	0.0018	-0.0053	0.0048**	-0.0004
Professional status	-0.0354**	0.0067***	-0.0287*	-0.0221	0.0079***	-0.0143
Educational level	0.0967***	0.0118***	0.1085***	0.0774***	0.0133***	0.0907***
Level 1 Theory of planned behavior						
Availability of private transport	0.0735***	(no path)	0.0735***	0.0873***	(no path)	0.0873***
Expected personal utility	(no path)	0.0028*	0.0028*	(no path)	0.0027	0.0027
Level 2 Built environment attributes						
Employment density	-0.0430	-0.0073***	-0.0503	-0.1176***	-0.0128***	-0.1304***

TABLE 8.1 Direct, indirect and total effects of the estimated multilevel structural equation models: models 1-P1 and 2-P2

	NON-WORK-RELATED TRAVEL					
	MODEL 1-P1 (FIGURE 8.5)			MODEL 2-P2 (FIGURE 8.6)		
	DIRECT EFFECTS[A]	INDIRECT EFFECTS[A]	TOTAL EFFECTS[A]	DIRECT EFFECTS[A]	INDIRECT EFFECTS[A]	TOTAL EFFECTS[A]
	-0.0354**	-0.0162***	-0.0516***	-0.0237	-0.0204***	-0.0441***
	-0.1033***	0.0072**	-0.0961***	-0.0876***	0.0089***	-0.0786***
	0.0322	-0.0019	0.0303	0.0251	-0.0025	0.0227
	-0.0563***	0.0036**	-0.0527***	-0.0473***	0.0045***	-0.0427***
	-0.0408**	0.0046**	-0.0362*	-0.0318*	0.0057***	-0.0261
	-0.0189	0.0089**	-0.0100	-0.0218	0.0112***	-0.1054
	0.1087***	0.0121**	0.1208***	0.0939***	0.0152***	0.1091***
	0.0531***	(no path)	0.0531***	0.0666***	(no path)	0.0666***
	(no path)	-0.0009	-0.0009	(no path)	-0.0014	-0.0014
	0.0441	-0.0046**	0.0395	0.0357	-0.0066***	0.0291
	-0.0768***	0.0056	-0.0711***	-0.0817***	0.0032**	-0.0785***
	-0.0393**	0.0048***	-0.0346*	-0.0352**	0.0041***	-0.0309*
	-0.0144	-0.0079	-0.0224	-0.0005	-0.0080	-0.0086
	-0.0982***	0.0016	-0.0966***	-0.0596***	0.0063	-0.0532***
	-0.3212***	0.0095	-0.3118***	-0.2059***	0.0048***	-0.2011***
	0.0551*	-0.0042	0.0509*	0.0315	-0.0086	0.0229
	-0.1067***	-0.0044	-0.1110***			
	-0.0521***	0.0055	-0.0466***			
				-0.4470***	-0.1632***	-0.6103***
				0.5410***	-0.0132***	0.5277***
	-0.0410**	-0.0178***	-0.0587***	-0.0300*	-0.0224***	-0.0525***
	-0.0757***	0.0079***	-0.0677***	-0.0645***	0.0098***	-0.0547***
	0.0314	-0.0021	0.0294	0.0258	-0.0027	0.0230
	-0.0589***	0.0040**	-0.0549***	-0.0493***	0.0049***	-0.0442***
	-0.0419**	0.0050**	-0.0369**	-0.0374**	0.0063***	-0.0311*
	-0.0139	0.0098***	-0.0041	-0.0144	0.1238***	-0.0019
	0.1049***	0.0133***	0.1182***	0.0833***	0.0167***	0.1000***
	0.0583***	(no path)	0.0583***	0.0732***	(no path)	0.0732***
	(no path)	-0.0010	-0.0010	(no path)	-0.0015	-0.0015
	0.0760*	-0.0050**	0.0710*	-0.0046	-0.0073***	-0.0118

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ENDOGENOUS VARIABLES	WORK-RELATED TRAVEL					
	MODEL 1-P1 (FIGURE 8.3)			MODEL 2-P2 (FIGURE 8.4)		
	DIRECT EFFECTS[A]	INDIRECT EFFECTS[A]	TOTAL EFFECTS[A]	DIRECT EFFECTS[A]	INDIRECT EFFECTS[A]	TOTAL EFFECTS[A]
Level 2 Built environment attributes						
Land-use mix	-0.1136***	-0.0159*	-0.1296***	-0.0883***	-0.0315***	-0.1198***
Job-housing ratio	-0.0393**	-0.0050***	-0.0444**	-0.0312*	-0.0181***	-0.0493***
Distance to the nearest public-transit station	-0.1042	0.0074	-0.0030	0.0035	0.0335***	0.0371*
Δ Distance to the nearest highway entrance/exit (infrastructure improvements 1991-2001)	0.0616**	0.0089***	0.0705***	-0.0336	-0.0194***	-0.0502**
Presence of urban amenities	-0.1063***	-0.0103	-0.1166***	-0.0722***	-0.0221***	-0.0943***
Distance to the coast	-0.0943***	0.0017	-0.0926***	0.0124	0.0355***	0.0479*
Level 2 Polycentricity						
Distance to Barcelona (central city)	0.1488***	0.0383**	0.1870***			
Distance to the nearest secondary center (inverse)	-0.0781***	-0.0177*	-0.0957***			
Trip origin in a center				-0.1957***	-0.1544***	-0.3500***
Trip destination in a center				0.2726***	-0.0170***	0.2555***
CO_2 emissions per capita < determinants						
Level 1 Individual-specific characteristics						
Gender	-0.0517***	-0.0649***	-0.1167***	-0.0567***	-0.0690***	-0.1258***
Age	0.0119	0.0309***	0.0428**	0.0010	0.0330***	0.0340**
nº of household members	0.0014	-0.0122***	-0.0108	0.0079	-0.0135***	-0.0055
nº of children (4- years)	0.0512***	0.0143***	0.0655***	0.0440***	0.0155***	0.0596***
nº of teenagers (4-16 years)	0.0211	0.0102**	0.0313	0.0184	0.0115***	0.0299
Professional status	-0.0325*	0.0177***	-0.0148	-0.0200	0.0188***	-0.0012
Educational level	0.0757***	0.0312***	0.1069***	0.0577***	0.0317***	0.0894***
Level 1 Theory of planned behavior						
Availability of private transport	0.1939***	(no path)	0.1939***	0.2068***	(no path)	0.2068***
Intention to use public transport	-0.0052	(no path)	-0.0052	-0.0073	(no path)	-0.0073
Intention to use private transport	0.0229*	(no path)	0.0229*	0.0229*	(no path)	0.0229*
Expected personal utility	(no path)	0.0108**	0.0108**	(no path)	0.0092**	0.0092**
Level 2 Built environment attributes						
Employment density	-0.0431	-0.0193***	-0.0624*	-0.1167***	-0.0305***	-0.1471***
Land-use mix	-0.1161***	-0.0210**	-0.1371***	-0.0910***	-0.0340***	-0.1250***
Job-housing ratio	-0.0113	-0.0063***	-0.0176	-0.0040	-0.0204***	-0.0244
Distance to the nearest public-transit station	0.0337	0.0076	0.0413*	0.0472**	0.0385***	0.0858***
Δ Distance to the nearest highway entrance/exit (infrastructure improvements 1991-2001)	0.0830***	0.0199***	0.1029***	-0.0094	-0.0173**	-0.0267
Presence of urban amenities	-0.0475*	-0.0128*	-0.0602**	-0.0151	-0.0249***	-0.0400
Distance to the coast	-0.0880***	0.0021	-0.0859***	0.0183	0.0401***	0.0584**
Level 2 Polycentricity						
Distance to Barcelona (central city)	0.1515***	0.0596***	0.2111***			
Distance to the nearest secondary center (inverse)	-0.0770**	-0.0224**	-0.0994***			
Trip origin in a center				-0.1870***	-0.1298***	-0.3168***
Trip destination in a center				0.2535***	-0.0230***	0.2304***

TABLE 8.1 Direct, indirect and total effects of the estimated multilevel structural equation models: models 1-P1 and 2-P2

****, **, * effects significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1), respectively. a. Direct, indirect, and total effects shown here are for the standardized solution (unstandardized solution are available on request).*

	NON-WORK-RELATED TRAVEL					
	MODEL 1-P1 (FIGURE 8.5)			MODEL 2-P2 (FIGURE 8.6)		
	DIRECT EFFECTS[A]	INDIRECT EFFECTS[A]	TOTAL EFFECTS[A]	DIRECT EFFECTS[A]	INDIRECT EFFECTS[A]	TOTAL EFFECTS[A]
	-0.0740***	0.0142	-0.0598***	-0.0508**	-0.0053***	-0.0561***
	-0.0257	0.0086***	-0.0172	-0.0189	-0.0017***	-0.0206
	-0.0168	-0.0135*	-0.0302	0.0042	0.0017	0.0059
	-0.1003***	0.0022	-0.0981***	-0.1573***	-0.0025	-0.1598***
	-0.1785***	0.0170*	-0.1615***	-0.1104***	-0.0019***	-0.1123***
	0.0121	-0.0075	0.0046	0.0697***	0.0035	0.0732***
	0.1035***	-0.0158	0.0877***			
	-0.0739***	0.0139	-0.0600***			
				-0.4149***	-0.1031***	-0.5180***
				0.4801***	-0.0110***	0.4691***
	-0.0229	-0.0589***	-0.0818***	-0.0141	-0.0628***	-0.0768***
	-0.0689***	0.0261***	-0.0428**	-0.0596***	0.0274***	-0.0322*
	0.0144	-0.0069	0.0075	0.0099	-0.0076*	0.0023
	-0.0581***	0.0132***	-0.0449***	-0.0510***	0.0139***	-0.0371**
	-0.0363*	0.0167***	-0.0196	-0.0318*	0.0175***	-0.0143
	-0.0145	0.0324***	0.0179	-0.0159	0.0346***	0.0187
	0.0647***	0.0442***	0.1088***	0.0501	0.0467***	0.0969***
	0.1932***	(no path)	0.1932***	0.2050***	(no path)	0.2050***
	0.0117	(no path)	0.0117	0.0156	(no path)	0.0156
	0.0585***	(no path)	0.0585***	0.0581***	(no path)	0.0581***
	(no path)	0.0176***	0.0176***	(no path)	0.0177***	0.0177***
	0.0455	-0.0167**	0.0288	0.0009	-0.0203***	-0.0194
	-0.0699***	0.0052	-0.0648***	-0.0593***	-0.0036	-0.0629***
	0.0317*	0.0035***	0.0352*	0.0365**	-0.0027***	0.0336**
	0.0776***	-0.0092	0.0684***	0.0917***	0.0015	0.0932***
	-0.0907***	0.0040	-0.0866***	-0.1088***	-0.0042	-0.1130***
	-0.1084***	0.0069	-0.1015***	-0.0499**	-0.0032***	-0.0531**
	0.0243	-0.0030	0.0213	0.0467*	0.0057	0.0524**
	0.0231	-0.0112	0.0219			
	-0.0471**	0.0032	-0.0439**			
				-0.3098***	-0.0657***	-0.3755***
				0.3769***	-0.0164***	0.3605***

The finding that greater proximity to centers (central city and secondary centers) tends to generally reduce travel behavior externalities could also explain the results achieved in model 2-P2, where the effects of the size of centers have been considered instead of the effects of proximity to centers. In this case, the net elasticity of trip origin in a center (i.e., the trips of people living in centers) and trip destination in a center (i.e., the trips of people oriented toward centers) show that whereas a trip starting in a center leads to much less negative travel behavior externalities, a trip ending in a center leads to greater negative travel behavior externalities. For example, the trip distance and time of individuals living in a center and the CO_2 emissions caused when those individuals travel are 49.33% [exp(0.4010) - 1], 41.91% [exp(0.3500) - 1], and 37.27% [exp(0.3168) - 1] lower compared to the trip distance, trip time, and CO_2 emissions of residents of non-center areas (trips starting in peripheral areas and centers' neighboring areas). In this regard, this finding, in combination with the previous finding on the effects of proximity to centers, may support the idea that developing strong transportation networks that can efficiently serve centers (not including the central city), and more strongly concentrating new urban developments in those networks would be a desirable planning policy solution to mitigate both congestion and the travel behavior externalities considered in this study.

Non-work-related travel

The rightmost columns of Table 8.1 and Figures 8.5 and 8.6 present our findings for non-work-related travel, including trips made for shopping, leisure, education, social (visiting), and health purposes. In terms of the total effects of individual-specific characteristics, individuals' travel-related attitudes, built environment attributes and polycentricity for non-work-related travel, it is remarkable that the signs and significance levels for most of these effects remain the same compared to the estimates for work-related travel (Figures 8.3-8.4). However, the magnitude of the net elasticity shrinks considerably for some individual-level determinants (e.g., gender) and municipal-level factors (e.g., land-use mix, job-housing ratio) indicating that their effect on travel behavior externalities is less relevant for non-work travel. In addition, it is important to note the following four nuances when considering the issue of non-work-related travel.

First, being older, having small children and, to a somewhat lesser extent, having teenagers in a household are all associated with shorter trip times, trip distances, and lower CO_2 emissions. The fact that non-work travel affords individuals a greater choice among a wider array of places to perform their daily activities as compared to work travel might explain why older residents and households with children or teenagers prefer to travel to closer locations if they have the opportunity. Second, the role played by infrastructure improvements (i.e., significantly negative elasticities for models 1-P1 and 2-P2) confirms the hypothesis advanced for the conceptual model, as shown in Figure 8.1. Infrastructure improvements leading to accessibility gains could foster the intention of the residents who enjoy these gains to travel toward cities with a wider variety and quantity of urban functions that have become more accessible, but that may remain a significant distance from their current locations. Third, the effect of proximity to the central city is not significantly associated with lower (or higher) transportation-related CO_2 emissions. Perhaps the influence exerted by the effects of proximity on secondary centers, which have increasingly concentrated a greater number of urban functions since 1991 (as shown in chapter 6), may explain this loss of importance in the role played by the central city. Fourth, the net elasticities of the effects of the size of centers have become considerably more prominent. For instance, a trip that starts in a center requires 84.10% [exp(0.6103) - 1] less trip time, is 67.87% [exp(0.5180) - 1] less lengthy, and is 45.57% [exp(0.3755) - 1] more sustainable in terms of CO_2 emissions than when it starts in a non-center area. This could be explained by the fact that centers are better able to satisfy their residents' non-work needs than their work needs. The next subsection presents detailed results on the direct and indirect effects of polycentricity to depict the importance of polycentricity's composite effects (i.e., it explores the connection between polycentricity and built environment attributes).

Effects of proximity to centers

The direct elasticity between distance to the central city and trip time, trip distance, and CO_2 emissions is quite substantial; moreover, it is higher for work-related travel than for non-work-related travel. All else being equal, a 10% increase in the distance to the central city is associated with a 1.38% (1.07%) decrease in trip time, a 1.49% (1.04%) increase in trip distance, and a 1.52% (0.02%) increase in CO_2 emissions for work (non-work) travel. These significant direct effects on trip time, trip distance and CO_2 emissions for work-related travel are (to some extent) offset or further enhanced by positive indirect effects, yielding a net elasticity of -0.0908 (trip time), 0.1870 (trip distance), and 0.2111 (CO_2 emissions), respectively. It is important to note that the magnitude of these indirect effects is relevant, representing at least 20% of the total effect or offsetting the direct effect by approximately one-third. For example, the net significant indirect effect of distance to the central city on trip time mediated through employment density, the job-housing ratio, and private transport availability is 0.0468[35]. This seems to show that possible congestion effects along the radial transportation axes toward the central city discussed above are mitigated by the indirect influence of the effects of proximity to the central city that result from higher urban-density settings, a greater balance between economic and residential functions, and the decreased availability of private transport as urban areas locate closer to the central city.

That said, the indirect effects of proximity to the central city operating through these three intermediate variables are related to a higher trip time (-0.0044), trip distance (-0.0158), and CO_2 emissions (-0.0112) when non-work travel is considered. The composition of these effects shows that the positive sign of job density with travel behavior externalities for non-work trips is the most responsible for the negative sign of the net indirect effects of the distance to the central city. For example, by analyzing the highest net indirect effects of the distance to the central city, which is -0.0158 for trip distance, the results reveal that the positive effects mediated through the job-housing ratio (-0.1265 x -0.0257) and the availability of private transport to individuals [(0.0623 x 0.0583) + (-0.3049 x -0.0863 x 0.0583) + (-0.1265 x 0.1207 x -0.0863 x 0.0583)] cannot compensate for the negative effects operated through job density [(-0.3049 x 0.0760) + (-0.1265 x 0.1207 x 0.0760)]. One plausible reason for this positive direct effect of density (e.g., 0.0760) is that urban areas with more urban amenities are also highly dense (Figure 8.5 shows that the elasticity of amenities on density is 0.2390), which results in those areas' greater exposure to traffic congestion, which leads to greater negative travel behavior externalities.

The direct effects of the distance to the nearest secondary center are similar to the distance to the central city's effects, where two nuances must be observed. The effects of proximity to the nearest secondary center are much more moderate and unaffected by congestion externalities. All else being equal, a 10% increase in the distance to the nearest secondary center is associated with a 0.46% (0.52%) increase in trip time, a 0.78% (0.74%) increase in trip distance, and a 0.77% (0.47%) increase in CO_2 emissions for work (non-work) travel. Moreover, these significant positive direct effects are increased by positive and significant indirect effects for work trips, whereas they are offset by negative and insignificant indirect effects for non-work travel, also because of the role of employment density explained above. In this regard, it is worth noting the importance of the net elasticity of these indirect effects for work travel, which accounts for at least 18% of the total effect of the distance to the nearest secondary center.

35 [(-0.3892 x -0.0509) + (-0.3893 x -0.0993 x 0.0763) + (-0.1407 x -0.0733) + (-0.1407 x 0.1002 x -0.0509) + (-0.1407 x 0.1002 x -0.0993 x 0.0763) + (0.1692 x 0.0763)].

Effects of the size of centers

The direct elasticity between trip origin in a center and trip time, trip distance, and CO_2 emissions is considerable, and it is higher for non-work-related travel than for work-related travel. All else being equal, when a trip is started in a center, the trip time and distance traveled by a center's residents, along with the CO_2 emissions generated when they travel for work (non-work) purposes, are reduced by 20.35% (56.36%), 21.62% (51.42%), and 20.56% (36.32%)[36]. These significant direct effects on trip time, trip distance, and CO_2 emissions for work (non-work) travel are increased by significant indirect effects, yielding a total effect of -0.4010 (-0.6103), -0.3500 (-0.5180), and -0.3168 (-0.3755), respectively. It is important to note that the magnitude of these indirect effects are quite substantial, representing at least 40% and 17% of the total effect for work and non-work travel, respectively. Moreover, these significant indirect effects confirm the hypothesis advanced by the conceptual model in section 8.4, which is based on the notion centers are those cities in a metropolitan area with built environment attributes; those attributes provide center's residents with access to their daily activities more quickly, from a shorter distance, in less time, and through the use of more sustainable transportation modes. For instance, the net significant indirect effect of trip origin in a center on CO_2 emissions for work travel, operating through job density, land-use mix, job-housing ratio, urban amenities, and private transport availability, is -0.1298[37]. This reveals that when a trip is started in a center, there is a higher-density urban setting, land-use mix and job-housing ratio, a greater presence of urban amenities, and lower availability of private transport, which in turn indirectly decrease the CO_2 emissions generated during daily travel.

The magnitude of the direct effects of trips ending in a center are quite similar to the direct effects of trip originating in a center; however, such trips foster greater travel behavior externalities instead of reducing them for work and non-work-related travel. When a trip has a destination in a center, the trip time and distance traveled and the CO_2 emissions from transportation for work (non-work) trip purposes are increased by 29.94% (71.77%), 31.34% (61.62%), and 28.85% (45.78%), respectively. This could be explained by the fact that centers not only attract population from their neighboring cities, which reduces travel behavior externalities because their aforementioned effects of proximity but also could attract many individuals living further away, which therefore could greatly increase travel behavior externalities for work and non-work travel. Nevertheless, these positive significant indirect effects on trip time, trip distance, and CO_2 emissions for work (non-work) travel are offset by negative indirect effects mediated through built environment attributes, resulting in a total effect of 0.2411 (0.5277), 0.2555 (0.4691), and 0.2304 (0.3605), respectively. In this regard, although the indirect effects of a trip destination in a center are less important compared to the effects when a trip is started in a center, these indirect effects could offset the direct effects by one-eleventh in some situations (e.g., with respect to CO_2 emissions and work trips). Consequently, the relevant magnitude of the net indirect effects of distance to the central city, distance to the nearest secondary center and trip origin in a center, and to a lesser extent, the indirect effects of trip destination in a center, has empirically substantiated the proposition that it is important to consider the composite effects of polycentricity to avoid either underestimating or overestimating its total effects.

36 The elasticity of a dummy variable is not the direct standardized coefficient. In a log-log model, the elasticity of a dummy variable is calculated by [exp(coefficient) - 1].

37 [(0.2199 x -0.1167) + (0.2199 x -0.1472 x 0.2068) + (0.4141 x -0.0910) + (0.4141 x 0.0230 x -0.1167) + (0.4141 x 0.2030 x -0.1472 x 0.2068) + (0.4141 x 0.0841 x -0.0040) + (0.4141 x 0.0841 x 0.1386 x -0.1167) + (0.4141 x 0.0841 x 0.2030 x -0.1472 x 0.2068) + (0.4141 x -0.0101 x 0.2068) + (0.1086 x -0.0040) + (0.1086 x 0.1386 x -0.1167) + (0.1086 x 0.1386 x -0.1472 x 0.2068) + (0.6798 x -0.0151) + (0.6798 x 0.1695 x -0.1167) + (0.6798 x 0.1695 x -0.1472 x 0.2068) + (-0.0764 x 0.2068)].

Multilevel modeling: random-intercept predictions

One way to check the previous findings' robustness is to illustrate how trip distance, trip time, and CO_2 emissions for work and non-work travel varies between the 164 municipalities in the Barcelona metropolitan region. To do so, this study builds on the multilevel modeling framework explained in section 8.5 (see equation 8.2) and estimates an intercept-only model—i.e., a model including only random terms—by using a maximum likelihood estimator to then predict residuals from the fixed intercept for each municipality.

Random-intercept predictions could be viewed as a measure of performance because they shed more light on which municipalities most effectively mitigate the travel behavior externalities considered in this research. Following Skrondal and Rabe-Hesketh (2009), this study uses Empirical Bayes predictions to compute the residuals at municipal-level. The Empirical Bayes predictions with marginal prediction error standard deviation (comparative standard errors) expressly enable a comparison of clusters. Figures 8.7 and 8.8 display these residuals in rank order for the 164 municipalities with respect to both work and non-work travel. It does not matter whether the predicted fixed part of the multilevel regressions were added; the ranking of municipalities would not have been affected. The bars indicate the 95 percent confidence interval for the predictions. The random-intercept predicted for a municipality is significantly different from the Barcelona metropolitan region's average if the 95 percent confidence interval does not intersect with 0 (dotted line). Thus, the lower the rank of a municipality, the higher its reduction in travel behavior externalities, regardless of whether its random-intercept prediction is also significantly different from the average for the Barcelona metropolitan region.

A comparison of these residuals shows that the variation among municipalities is larger for CO_2 emissions than for trip distance and time, and it is larger for work travel than for non-work trips, as indicated by the y-axis of Figures 8.7 and 8.8. Furthermore, the random-intercepts for most centers (central city and secondary centers) are significantly below the Barcelona metropolitan region's average, particularly in terms of CO_2 emissions. The rank orders of the 164 municipalities classified into central city, secondary centers, centers' neighboring areas, and peripheral areas differs somewhat. Only the central city of Barcelona occupies exactly the same position: first place in both trip time and trip distance, and second place in CO_2 emissions. However, the extremes on the low and high ends are roughly similar. Whereas trip distance, trip time, and CO_2 emissions are generally highest in peripheral areas and in some centers' neighboring areas, these travel behavior externalities tend to be lower for the central city, particularly for the secondary centers of Vilanova I la Geltrú, Sabadell, Mataró, Martorell, and Terrassa. These short distances and times, along with the lower emissions for most centers, could be attributed to their local built environment attributes such as greater compactness (density), mixed-land use, or presence of urban amenities; accordingly, these results could reinforce the previous analysis of the direct and indirect effects of polycentricity. In comparison, the combination of compactness, more restricted availability of development sites and a location close to the radial transportation axes oriented toward the central city seem to culminate in high congestion levels for centers such as L'Hospitalet de Llobregat and Cornellà de Llobregat, whose residents thus experience decreased travel speeds and increased trip times.

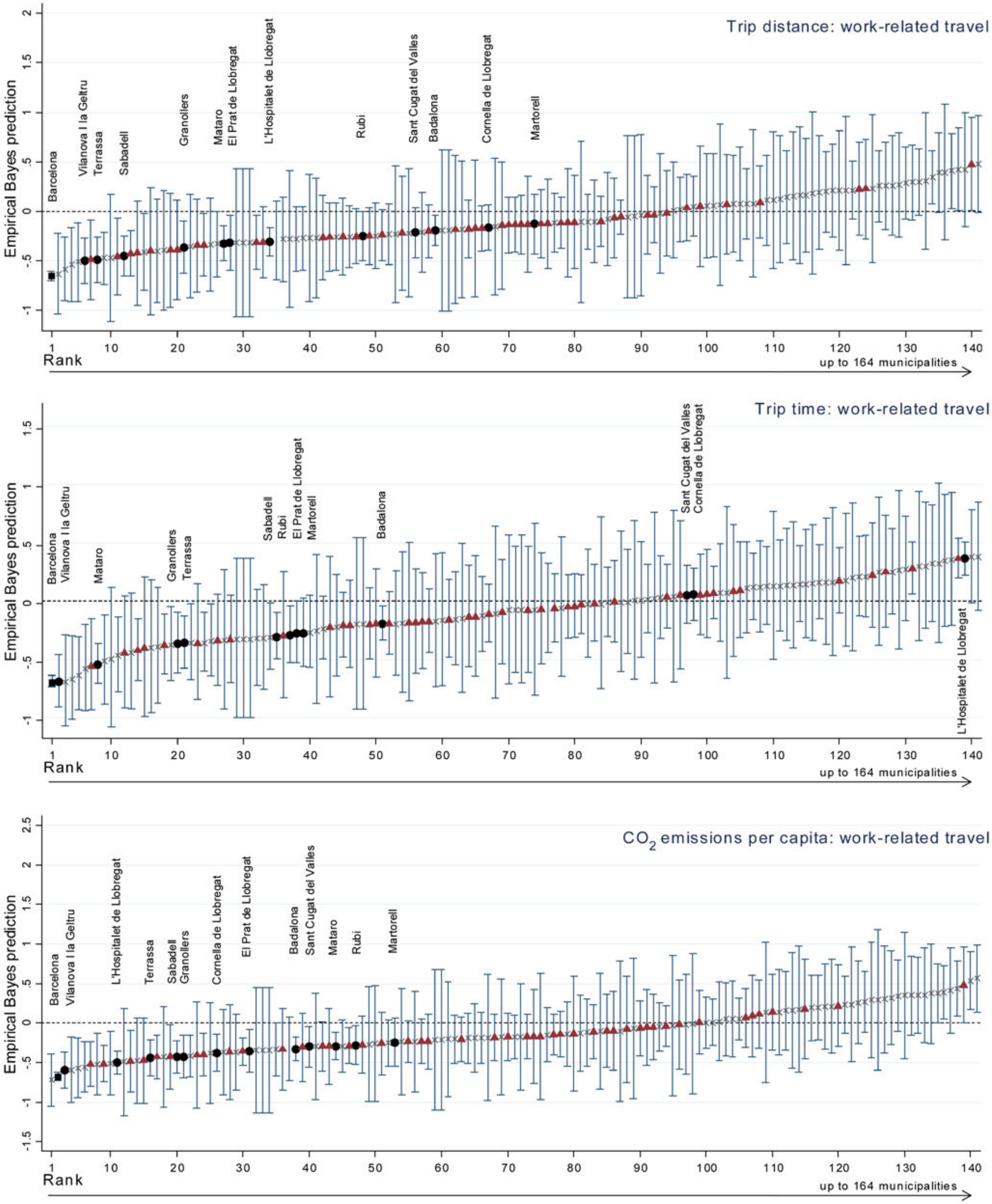


FIGURE 8.7 Caterpillar plot of random-intercept predictions (Empirical Bayes) and approximate 95% confidence intervals versus ranking for trip distance, trip time, and CO_2 emissions per capita for work-related travel

Legend: the bar/s with black square display/s the estimated residuals for the central city (Barcelona), with black circles for the secondary centers, maroon triangles for centers' neighboring areas, and gray crosses for peripheral areas.
Note(s): only the first-ranked 140 municipalities are displayed, and centers' (central city and secondary centers) identifiers are shown on top of confidence intervals.

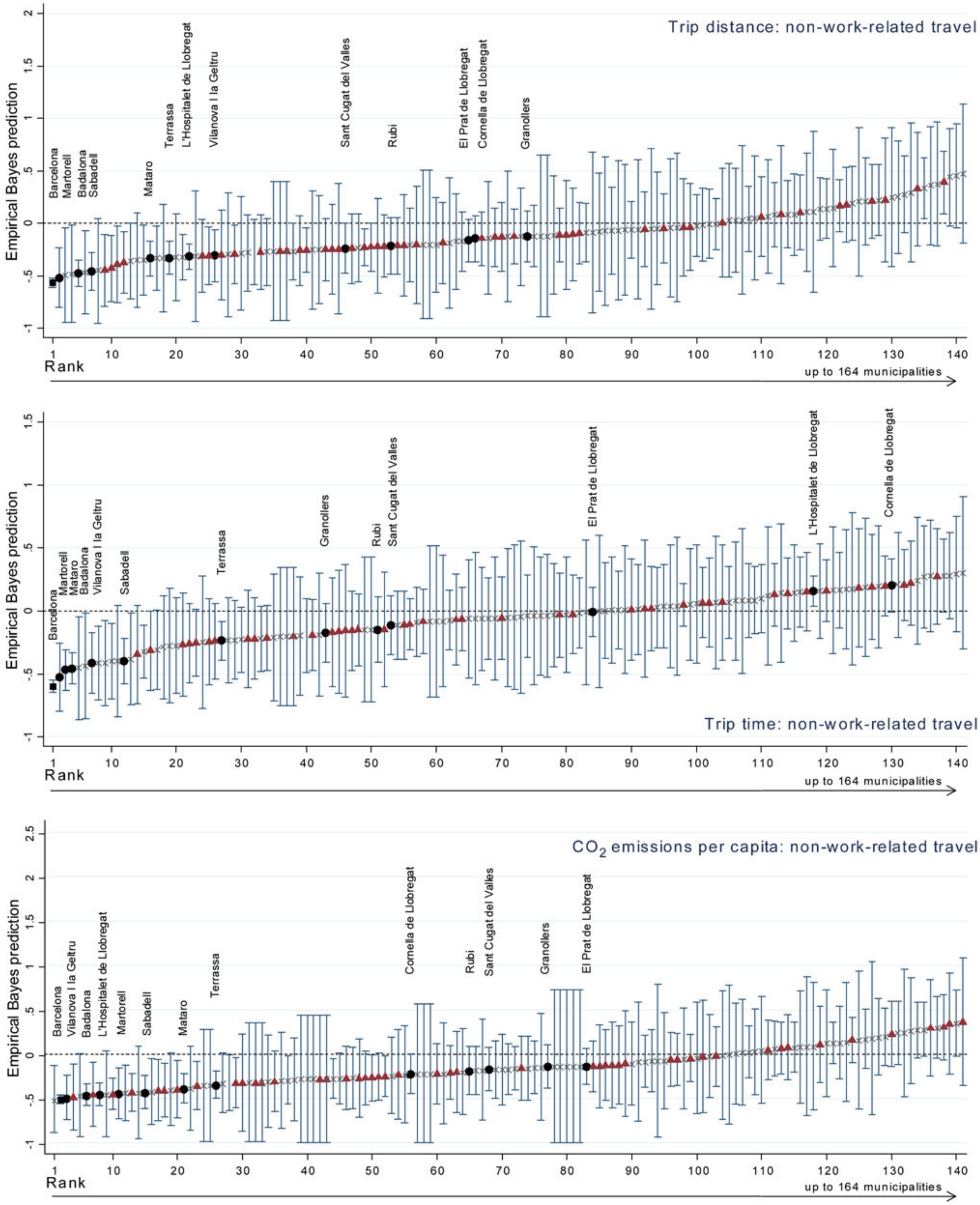


FIGURE 8.8 Caterpillar plot of random-intercept predictions (Empirical Bayes) and approximate 95% confidence intervals versus ranking for trip distance, trip time, and CO_2 emissions per capita for non-work-related travel

Legend: the bar/s with black square display/s the estimated residuals for the central city (Barcelona), with black circles for the secondary centers, maroon triangles for centers' neighboring areas, and gray crosses for peripheral areas.
Note(s): only the first-ranked 140 municipalities are displayed, and centers' (central city and secondary centers) identifiers are shown on top of confidence intervals.

Multilevel modeling: random intercept models

Another method of checking for robustness is to estimate a set of random intercept models to examine how the impacts of the determinants considered in this study on trip time, trip distance, and CO_2 emissions for work and non-work travel vary when the composite (direct and indirect) associations have not been considered. To do so, this research also builds on the multilevel modeling framework explained in section 8.5 (see equation 8.2) and estimates a set of multilevel regressions following the research design proposed by chapter 7, which was based on four different model specifications[38] to examine the link between travel mode choice and polycentricity. These four model specifications regarding the determinants on trip distance, trip time, and CO_2 emissions per capita for work and non-work travel are reported in Appendices 8.1-8.3, respectively.

Essentially, these random intercept models reveal that among those determinants, which are statistically significant for trip distance, trip time, and CO_2 emissions (insignificant determinants are not reported), they generally present the expected signs, as in the estimated multilevel structural equation models. However, the magnitude of the effects in these multilevel regressions, which could represent the direct effects in a multilevel structural equation model, is larger than when multilevel structural equation models were estimated. This confirms what the econometric literature (e.g., Preacher et al., 2010, 2011) has stated relative to the fact that multilevel structural equation modeling has the main advantage over multilevel regressions with respect to obtaining less-biased estimates when hierarchical data are used.

Focusing on explaining the effects of polycentricity, these random intercept models reveal that proximity to centers, the size of centers, and the aggregate size of centers through their integration exert an important influence on reducing trip distance, trip time, and CO_2 emissions for work and non-work travel. Indeed, as in the estimated multilevel structural equation models, the magnitude of most of the effects of polycentricity is larger than that of other individual-level covariates, such as professional status or household attributes. However, two important nuances can be observed. First, the signs of the categorical variables 'trip origin' and 'trip destination' corroborate the finding that travel behavior externalities are sharply reduced when a trip starts in a center (central city and secondary centers), whereas when a trip ends in a center, the trip distance, trip time, and transportation-related CO_2 emissions are increased. Second, the results obtained when the effects of the aggregate size of centers through their integration are considered support the explanation (given above) when discussing the positive sign of the variable 'trip destination in a center' that is included in the estimated multilevel structural equation models. Whereas central-city-to-central-city, secondary-centers-to-secondary-centers, and centers'-neighboring-areas-to-centers'-neighboring-areas trips greatly reduce travel behavior externalities compared to peripheral-areas-to-peripheral-areas trips, the other trip combinations (e.g., peripheral-areas-to-central city trips) foster greater negative travel behavior externalities. This confirms that the positive sign of a 'trip destination in a center' is related to the fact that trips made by individuals near centers, which significantly reduce travel behavior externalities because of the positive effects of proximity to centers, cannot compensate for the negative effects related to centers' ability to attract people who live further away.

38 These four model specifications are built on adding level-2 variables to a baseline model formed by individual-specific characteristics (level-1 variables) following the research approach of chapter 7 in this manner: model 1 includes built environment attributes, model 2 adds polycentricity variables regarding the effects of proximity to centers, model 3 includes polycentricity variables focusing on the effects of the size of centers, and model 4 considers the effects of the aggregate size of centers through their integration.

§ 8.7 Conclusion and discussion

This chapter aimed to examine the extent to which Barcelona's polycentric metropolitan structure influences the occurrence of social and environmental externalities related to travel. The main research question guiding this aim was as follows: To what extent does polycentricity reduce trip distance, travel time and transportation-related CO_2 emissions, and how can its effects be realized in planning practice? In elaborating this research question, this study has proposed a conceptual model and applied an empirical framework that address the relevant issues and biases identified in the literature, thereby (perhaps) explaining the discrepancies in research findings on the relationship between polycentricity and travel behavior externalities found in the literature.

The conceptual model has contributed to identifying complex and multiple relationships between polycentricity and negative travel behavior externalities. These relationships involve both direct and indirect effects because polycentricity has an impact on built environment attributes. These composite effects of polycentricity required us to establish the associations between the morphological and locational characteristics of urban areas and polycentricity. In addition, the conceptual model accounted for the composite (direct and indirect) effects of the built environment and travel behavior externalities on the one hand, and the multiple links between individuals' attitudes encapsulated in the theory of planned behavior, individuals' sociodemographic attributes and travel behavior externalities on the other hand.

This is one of the first studies of polycentricity and travel behavior to use multilevel structural equation modeling. This method helps avoid the risk of ecological fallacy that exists in aggregate data analyses and allows the use of hierarchical data without the risk of potentially biased estimation results. Furthermore, it has allowed both the identification and disentanglement of complex causal relationships as well as the measurement of variables that are neither observable nor directly measurable, such as trip makers' intention to use public transport. Moreover, it is not common to apply this method to work-related and non-work-related travel separately. Finally, the consideration of the three distinct dimensions of a polycentric spatial configuration that play a role in the development of agglomeration benefits in a metropolitan area—following chapters 2 and 7—and the centers identified in chapter 5 have enabled this research to build a more comprehensive and systematic empirical framework to attempt to unify the existing fragmented empirical research on the advantages of polycentricity and therefore, to achieve broader conclusions about its effects. Namely, the size of centers and the (geographic) proximity to centers were considered in the estimation of multilevel structural equation models, whereas the aggregate size of centers through their integration was considered when the findings were checked for robustness (i.e., in the estimated random intercept models). In other words, these three dimensions of a polycentric metropolitan structure were translated into model frameworks that examine the effects of being located in or oriented toward centers, of being located closer to these centers and of interaction patterns between centers.

The empirical analysis of travel behavior externalities has mainly revealed that a polycentric structure is significant and is positively associated with shorter trip distances, less travel time, and lower transportation-related CO_2 emissions for both work and non-work trips. Additionally, the estimates of the multilevel structural equation models indicate that the distance to centers and the type of city (i.e., which size have different categories of places: centers and non-center areas) exert a considerable effect on trip distance, trip time and CO_2 emissions. Although the magnitude of the net effects of polycentricity is moderate and as large as the individual-level determinants (e.g., private transport availability and educational level) when the effects of proximity to centers are considered, the net elasticities of polycentricity are considerably higher when the effects of the size of centers are considered, particularly with regard to non-work-related travel. Moreover, the results of these statistical models show that it is important to consider the composite (direct and indirect) effects of polycentricity operated through individual-level or built environment attributes to avoid underestimating its total effects. Whereas the significant indirect effects of being located close to centers represented at least 18-20% of the total effects, the significant indirect effects of being located in or oriented toward centers accounted for at least 17-40% of the total effects. This finding is of the utmost importance because it empirically substantiates that travel behavior is becoming more connected to the metropolitan structure as built environment attributes of urban areas such as employment density and the job-housing ratio, along with certain individual attributes such as private transport availability, were influenced by the existence of multiple centers in a metropolitan area. Put differently, this finding clarifies that the greater the proximity of residential areas to centers, the higher the employment density and the job-housing ratio of these residential areas and the lower the availability of private transport. This, in turn, results in a greater benefit for the residents of locations close to centers because greater compactness and proximity between economic and residential functions and lesser availability of private transport availability result in shorter travel times and trip distance and as a consequence, lower transportation-related CO_2 emissions. Of course, as shown by the estimates of the multilevel structural equation models, these benefits are even larger for the residents of centers themselves.

Implications for planning

The research findings from this chapter are relevant to spatial planning because they inform how the benefits of polycentricity can be realized in planning practice. In particular, the estimated effects (total, direct, and indirect elasticities along with Empirical Bayes predictions) of the link between polycentricity and travel behavior externalities provide evidence-informed knowledge for architects, planners and policymakers upon which policy recommendations for the spatial development of the Barcelona metropolitan region can be based. This study can fill a gap in the 2010 Barcelona Metropolitan Territorial Plan, which did not empirically test the economic, social, and environmental implications of its territorial development strategy, as explained in chapter 4. Two main evidence-informed policy recommendations can be formulated.

First, it seems reasonable that if policymakers pursue the policy objective of mitigating the negative social and environmental externalities of individuals' travel behavior, they should not only promote new urban developments in centers or in areas close to them but also attempt to increase their compactness and density, land-use mix and job-housing ratio. This policy recommendation, in turn, could contribute to the accomplishment of the 2010 Barcelona Metropolitan Territorial Plan's objective 12, which states as follows: "*making mobility a right... for citizens; the primary objectives are to increase accessibility and decrease trip distances and times*" (see Generalitat de Catalunya, 2010). However, policymakers should be aware that excessive new urban developments in the vicinity of the central city of Barcelona can have also contradictory effects because the research findings have noted a severe presence of congestion along the radial transportation axes to Barcelona, which in turn increases trip times for people going there. Indeed, Empirical Bayes predictions showed that those centers that are the least effective in mitigating trip times for work- and non-work-related travel are located close to Barcelona and linked to the radial transportation axis developed from the central city (e.g., L'Hospitalet de Llobregat).

Second, infrastructure developments and improvements could also be prioritized with the purpose of achieving shorter trip times, shorter trip distances and lower CO_2 emissions from transportation. In view of the findings, it seems sensible to prioritize those infrastructure proposals of the 2010

Barcelona Metropolitan Territorial Plan (see chapter 4) and others that are the most supportive of developing a strong transportation network aimed at efficiently increasing connectivity within and among centers (not including the central city). Indeed, random intercept models indicated that the type of interaction (i.e., between different categories of places: central city, secondary centers, centers' neighboring areas, and peripheral areas) exerts a larger effect on travel behavior externalities than the distance to centers, where trips between two secondary centers are shorter, take less time and cause less transportation-related CO_2 emissions compared to trips between two peripheral areas. Moreover, this planning policy can be supported by a strategy aimed at locating high-order amenities in accessible areas between centers and in combination with other amenities to address the negative impact of trips started in areas located further from centers and ending in centers (e.g., peripheral-areas-to-central-city and peripheral-areas-to-secondary-centers trips) because according to the research findings, a greater concentration of amenities is highly positively associated with lower negative externalities caused by work- and non-work related travel.

In a sense, these two evidence-informed policies shed light on how the benefits of polycentricity can be realized in planning practice. In chapter 9, which presents the conclusions of this thesis, these aforementioned evidence-informed policies are joined with the policies recommended in chapter 7 to provide more comprehensive policy recommendations for the Barcelona metropolitan region. Additionally, chapter 9 formulates answers to this dissertation's three general research questions (see the introduction) and ends with an agenda for both research and policy.

PART 5 Reflections on the triple Ps: polycentricity, performance and planning

9 Conclusions and agenda for research and policy

§ 9.1 Introduction

As stated in the introductory chapter large urban agglomerations are a complex spatial configuration of places and flows that are polycentric by nature. Recently, the focus on agglomerations' polycentric structure has attracted a great deal of attention from both researchers and policymakers, who must manage the economic, social, and environmental challenges that the population of these metropolitan agglomerations will experience in the coming decades.

In research, a considerable portion of the study of polycentric agglomerations has focused on the conceptualization of polycentricity on distinct territorial scales and the empirical analysis of its economic, social, and environmental (dis)advantages. In the policy realm, polycentric development appears to be the main hallmark of spatial plans for metropolitan areas worldwide. Some of the key policy objectives that polycentric development is expected to fulfill include offering an economical, efficient transportation system and a sustainable environment, along with extending access to education, jobs, amenities, and decent housing to a large number of people.

In chapter 1, it was argued that such objectives could only be achieved if numerous major, interrelated issues are further explored. First, various approaches to polycentricity co-exist in the absence of a high level of integration. One approach refers to polycentricity on the intra-urban (Davoudi, 2003), whereas another refers to polycentricity on the inter-urban (Davoudi, 2003). Moreover, when these approaches are integrated, they are often conflated, at least to an extent (Van Meeteren et al., 2015). Second, although many claims have been made about the economic, social, and environmental advantages of polycentricity on intra- and inter-urban scales, little has been proven (see, e.g., Burger, 2011; Lee, 2006a; Meijers, 2007a). Third, an improved understanding of polycentricity in research to address how polycentric development could be conceptualized in spatial plans and how the assumed benefits of polycentricity can be realized is still missing from current planning practices. Addressing these three issues has been the key motivation for this dissertation: to link the knowledge of polycentric constellations and their empirically tested implications for economic, social, and environmental aspects to planning practice and policy in metropolitan areas.

The overarching research goal of this thesis has been to contribute to the debate on polycentricity in the three interrelated issues mentioned above. First, it has aimed to renew the conceptualization of polycentricity by bringing together two distinct literatures, namely, the literature on intra-urban polycentricity and the literature on inter-urban polycentricity. Second, it has aimed to empirically substantiate the relationship between polycentricity and performance in metropolitan areas. Third, it has aimed to understand how the makers of spatial plans have addressed polycentric development and how the assumed benefits of polycentricity can be realized in planning practice. To accomplish these goals, this thesis has addressed the following three general research questions:

1. How has the conceptualization of polycentric development in spatial plans evolved over time, and what can be learned from this evolution?
2. How has polycentricity been conceptualized in research, and how can it inform planning practice?

3 To what extent does polycentricity foster better performance in a metropolitan area, and how can its effects be realized in planning practice?

Each of the preceding 6 chapters is based on independent research that answers a portion of the above three research questions. In answering these three questions, a set of specific research questions have been formulated by considering the Barcelona metropolitan region, which is the case study used in this thesis. These research questions are related to a different challenge or research gap arising from chapter 2's review of the state of the art on the triangular relationship between polycentricity, performance, and planning.

In this final chapter, the answers to the general research questions are formulated based on a summary of the research findings achieved in the previous chapters followed by a conclusion (section 9.2). Because of its length, the parts of these answers that are related to defining guidelines for planning policies are formulated in a separate section (section 9.3). Finally, this chapter ends with a research and policy agenda regarding the reciprocal relationships between polycentricity, performance, and planning in metropolitan regions (section 9.4).

§ 9.2 Research findings

How has the conceptualization of polycentric development in spatial plans evolved over time, and what can be learned from this evolution?

Chapters 3 and 4 presented the research findings related to the understanding of how makers of spatial plans have addressed polycentric development. The study of the planning proposals for Barcelona and Catalonia and the territorial model that they advocated has illustrated both the origin of the polycentric development vision in Catalonia's planning practice and a clear transition pattern in its conceptualization in successive spatial plans. Moreover, it has exposed some shortcomings in the application of a polycentric development strategy in spatial plans that stems from those plans' lack of attention to the ongoing academic debate on polycentricity and its link to the performance of metropolitan areas. That said, this study has also provided valuable lessons about which factors have influenced the definition of the polycentric territorial model in spatial plans and how research and policy are related. Such knowledge is important to enhance the effectiveness and feasibility of polycentric development in planning practice.

The roots of the polycentricity debate

The origin of a planning vision of polycentricity as a development strategy for Catalonia is rooted in the early 1930s. The 1932 *Pla de distribució en zones del territori català: Regional Planning* and the 1936 *Divisió Territorial de Catalunya* departed from a remarkable distrust of the city's industrialization by strong social, cultural, and political movements and advocated for a planning strategy to counter the increasing concentration of people and economic activities in the capital city of Barcelona. Although polycentric development was understood in the 1932 *Regional Planning* as a development strategy aimed at limiting Barcelona's growth through the decentralization of economic activities and population, the 1936 *Divisió Territorial de Catalunya* advocated for a set of central places across Catalonia's entire territory to limit the negative consequences of rapid urbanization caused by industrialization. The close connection between social, cultural, and political interests to address the negative consequences of cities' industrialization and the proposed spatial solution that took the shape of envisioning a polycentric territorial model marked a new chapter in subsequent spatial plans for Barcelona and Catalonia, as shown in chapter 3's policy/discourse analysis. During Spain's totalitarian regime (1939-1976) and afterwards, when democracy was restored, the makers of spatial plans perceived polycentric development as the best development strategy not only to overcome the urban-rural opposition between Barcelona (city) and Catalonia (countryside) but also to achieve a balanced territory in economic, social and environmental terms. Indeed, the analysis of the territorial model advocated by most of the spatial plans formulated between 1932 and 2010 concluded that they attempted to implement—with varying degree of success—a polycentric development strategy for Barcelona or Catalonia. The exception was the 1934 *Pla Macià* or *Nova Barcelona*, which was the single call to plan a monocentric Catalonia that would advance Barcelona as a national and international capital.

Transitions in the understanding of polycentric development

The polycentric territorial model of the successive planning proposals, beginning with the first plan (the 1953 *Pla Comarcal d'Ordenació Urbana de Barcelona*) and ending with the most recent plan (the 2010 *Pla Territorial Metropolità de Barcelona*) has changed in two important ways over the course of time. The first transition is that although polycentricity was first conceptualized as a decentralization strategy aimed at restricting Barcelona's growth, it later changed into a territorial model that could organize and canalize future urban development building on the urban dynamics themselves. This shift in the conceptualization of polycentric development in planning occurred between the 1950s and the early 1960s, when the impact of urbanization trends and a set of liberal, austere economic policies (e.g., the 1959 *Plan de Estabilización*) revealed that the goal of limiting Barcelona's city size resulted in an arduous assignment that required constant revisions of spatial plans. This novel polycentric development vision became clear in the territorial model of the 1966/1974 *Pla Director de l'Àrea Metropolitana de Barcelona*. In marked contrast with two preceding plans (the 1953 *Pla Comarcal d'Ordenació Urbana de Barcelona* and the 1959 *Pla General d'Ordenació de la Província de Barcelona*), this plan used estimated urban growth to define a polycentric territorial model based on both creating new centers and strengthening existing centers to absorb future urban growth. Moreover, this growth should take place in a territory larger than previously identified, crossing administrative borders and more closely resembling Barcelona's real metropolitan area.

The second transition involves the addition of a network perception to the vision on polycentric development, meaning that the focus broadened from centers to include their interrelationships. Several studies of urbanization dynamics that were prepared during the same period as the 1995 *Pla Territorial General de Catalunya* showed that the entire territory of Catalonia—including the capital city of Barcelona—should be understood as a single polycentric reality in which important functional interdependencies and complex hierarchies existed. Consequently, the network paradigm entered the debate and complemented the conceptualization of polycentric development, and the 1995 *Pla Territorial General de Catalunya* identified a polycentric network of cities both within and beyond the Barcelona metropolitan area. This network perception on polycentricity made a definite contribution to overcoming the antagonism between Barcelona (city) and Catalonia (countryside) because it integrated the capital city of Barcelona into a polycentric territorial model for the entire territory of Catalonia. Therefore, this was the first polycentric territorial model that could enable both the decentralization from Barcelona and the organization of urban growth without hampering the achievement of more balanced territorial development in Catalonia. In addition, the 1995 *Pla Territorial General de Catalunya* represented another new chapter in Catalonia's planning tradition. After the plan's approval, the coming spatial plans for a supramunicipal territory (e.g., the 2010 Barcelona Metropolitan Territorial Plan) built upon its vision of polycentric development based on a polycentric network of cities to define a territorial development strategy that achieves *sustainable development* (which should be broadly understood as the fulfillment of certain economic, social, and environmental objectives).

Weak empirical base

All of the territorial development strategies developed over many decades in Catalonia share an important characteristic, namely, deficiencies in the empirical base upon which the proposed polycentric territorial model rested, and little interest in establishing causal relations to evaluate how this polycentric model would foster the economic, social, and environmental objectives of a spatial plan. The policy/discourse analysis presented in chapter 3 revealed that traditionally, the general working method used by the elaborators of spatial plans in Catalonia involved developing a polycentric model by diagnosing ongoing urbanization trends (e.g., concentration of population, deconcentration of economic activities, etc.) and deriving the consequences of those trends (e.g., congestion, quality of life, etc.), followed by morphologically identifying a set of cities (or urban areas) in which future urban development should take place, which was assumed to achieve the plan's objectives.

This weak empirical base leads to several inconsistencies that were revealed when the most recently approved spatial plan for the Barcelona metropolitan region (the 2010 Barcelona Metropolitan Territorial Plan) was scrutinized in detail. Chapter 4 noted some discrepancies between the centers proposed by this plan's polycentric model (i.e., Barcelona and the cities of the *Arc Metropolità* (Metropolitan Arch)) and the places where the most urban growth had occurred in recent decades. The study of population dynamics revealed that the spatial plan had failed to identify several centers that should be considered important urban growth poles and that had canalized urban development in the last few decades. The spatial plan also relied heavily on urban size when identifying centers and their roles in the urban system (e.g., the roles given to the Metropolitan Arch's cities). Such a criterion obviously represents a greater departure from the interpretation of a polycentric system as a hierarchical system than from an interpretation corresponding to a network system, which nevertheless had inspired the polycentric development vision of the 2010 Barcelona Metropolitan Territorial Plan (as becomes clear in notions such as complementarity and a disconnection between size and function). As highlighted in chapter 4, increasing the effectiveness and feasibility of polycentric development in planning practice requires more research and empirical evidence on (1) how centers can be identified in a comprehensive manner and how the level of polycentricity can be measured on the metropolitan-region scale; and (2) the relationship between polycentricity and performance in a metropolitan area.

Lessons about polycentric development in the Catalonian context

Finally, both the careful examination of the 2010 Barcelona Metropolitan Territorial Plan (chapter 4) and the study of the conceptualization of polycentric development over time (chapter 3) noted two relevant insights that are needed to understand polycentric development in Catalonia's planning practice. First, factors that go beyond evidence such as political ideology, interests, and institutional tradition play an important role in policy development; consequently, they are also echoed in the definition of a particular territorial model. For instance, public consultation on the 2010 Barcelona Metropolitan Territorial Plan advanced the viewpoint that a larger set of cities in the Vallès Occidental region should be identified as centers given their importance in organizing the development of the Barcelona metropolitan region; moreover, this claim was supported by urban dynamics on the ground. However, with only one exception, the Plan's editors (who belong to the planning unit of the Catalan government, which was under socialist rule) identified as growth poles only cities that were ruled by the Socialist Party at the time of writing. Another example was the lack of political support for approving the 1966 *Pla Director de l'Àrea Metropolitana* because it delimited a metropolitan territory for Barcelona (approximately 3,000 square kilometers) that far overflows the legal-administrative borders that this spatial plan should have formally considered (the region of Barcelona defined by the 1953 *Pla Comarcal*, which comprised 485 square km), thus considering a part of the territory to fall within the jurisdiction of the Province of Barcelona. Other evidence for the relevance of such less tangible factors includes the strong political, social, and cultural concerns over and interests in avoiding industrialization (the 'gigantism' of Barcelona), which led both to the rise of a polycentric vision for Catalonia during the first third of the 20th century and to the strenuous objection to a monocentric alternative since that time.

Second, it is striking that over the course of time, all of the relevant centers that were identified using the novel method presented in chapter 5 have also been identified in spatial plans, albeit not simultaneously. This highlights the capability of the makers of the plans to use relevant conceptualizations that lead to their identification, thus suggesting that research and policy practice are perhaps not as separate or competitive as previously suggested, and policymakers do have an interest in territorial evidence.

Conclusion

Envisioning polycentric development in spatial plans has become a hallmark of planning practice in Catalonia. The first vision of polycentric development appeared in the 1930s as a response to the debate about the urban-rural opposition between Barcelona (city) and Catalonia (countryside) that resulted from increasing demands to address the (negative) challenges posed by cities' industrialization. Since then, the vision of polycentric development in spatial evolved, showing two transitions in its conceptualization in successive plans. The first transition was that although polycentricity was first conceptualized as a decentralization strategy aimed at restricting Barcelona's growth, it later changed into a territorial model to organize and canalize future urban development building on the urban dynamics themselves. The second transition involved the addition of a network perception to the vision on polycentric development. This network perception on polycentricity made a definitive contribution to overcoming the antagonism between Barcelona and Catalonia because it integrated the capital city of Barcelona into a polycentric territorial model for the entire territory of Catalonia.

The applications of polycentric development in various spatial plans in Catalonia also exposed some shortcomings stemming from spatial plans' prescriptive or normative approaches to defining polycentric development in which the empirical evidence related to existing territory was overlooked. However, the simultaneous consideration of all of the applications of polycentric development in spatial plans—and therefore, when the role played by factors other than evidence, such as interests and institutional policy traditions can be better disentangled—noted that some shortcomings in the definition of a polycentric development strategy can be explained by the fact that to a certain extent, plans are indeed politicized. This posed the challenge of building an understanding of polycentric development that was more closely connected to the ongoing academic debate on polycentricity and thus, a call for a more evidence-informed planning based on an improved knowledge of polycentricity, primarily respect for its conceptualization (identification and measurement) and effects on the economic, social, and environmental performance of metropolitan areas. Public and private actors influencing policy, for example, through their ideology or their own interests, would occupy a crucial role in the implementation of this understanding of polycentric development, based on considering (or not) the policy guidelines/recommendations that resulted from empirical evidence and aimed to improve the effectiveness and feasibility of spatial plans.

How has polycentricity been conceptualized in research, and how can it inform planning practice?

Chapters 5 and 6 aimed to renew the conceptualization of polycentricity by bringing together two distinct literatures, namely, the literature on intra-urban polycentricity and the literature on inter-urban polycentricity. The research findings from these two chapters inform spatial plans, primarily with respect to the effectiveness and feasibility of a polycentric development strategy. Chapter 5's findings revealed which method of identifying centers was the most accurate way to define the polycentric model in the Barcelona metropolitan region, whereas chapter 6's findings made complementary arguments to draw conclusions about the extent to which supporting a polycentric development strategy in a metropolitan region is convenient when that metropolitan region is not already polycentric.

The conceptualization of polycentricity

In chapter 5, it was argued that identifying centers in metropolitan areas by considering various pathways through which polycentricity emerges—specifically, the decentralization and the incorporation-fusion trajectories—is essential to define the polycentric model in a metropolitan area in a manner that is more accurate than either current empirical identification methods in the literature or the non-empirical approach of a spatial plan. Because the different origins of center formation have an impact on the nature of centers' agglomeration economies according to both the New Urban Economics and New Economic Geography framework, the identification of centers arising out of distinct trajectories becomes essential to best define the theoretical and empirical polycentric model adopted by the economics literature. In addition, a new theory-informed conceptualization of what a center is was added in chapter 5. Centers are considered to be the places that not only have the highest level of agglomeration economies in a metropolitan area but also cast the most wide-ranging (spatially), powerful agglomeration shadows over their surroundings.

The findings that resulted from evaluating the outcomes of different identification methods against their fit with the polycentric model, as suggested by the economics literature, revealed that the identification method proposed in chapter 5 performed better than the literature's current density- and flow-based methods. This was because centers identified using the method proposed in chapter 5 had a higher level of agglomeration economies and cast more severe agglomeration shadows. However, centers arising out of incorporation-fusion were characterized by a higher level of agglomeration economies and cast more spatially wide-ranging, powerful agglomeration shadows than did centers originating from decentralization. This better performance of the novel method to define the polycentric model that has been adopted by the economics literature also holds when comparing outcomes with the set of centers identified in the 2010 Barcelona Metropolitan Territorial Plan.

Additionally, the comparison of the outcomes of various identification methods with actual development on the ground (i.e., the location of urban projects since 1991 and land-use development between 1956 and 2006) noted that the better performance of the empirical method proposed in chapter 5 is particularly associated with the identification of, inter alia, Sant Cugat del Vallès, Rubí, and El Prat de Llobregat as centers arising out of decentralization, and of, inter alia, L'Hospitalet de Llobregat as centers arising out of incorporation-fusion. These centers were not identified in the 2010 Barcelona Metropolitan Territorial Plan, but it is these centers in particular that experienced major new urban development. Moreover, they have experienced a substantial transformation in land use over the course of time in accordance with their origin (decentralization or incorporation-fusion). In addition, their identification as centers of the Barcelona metropolitan region was justified by the findings of chapters 3 and 4. In many of the preceding spatial plans (e.g., 1966 *Pla Director de l'Àrea Metropolitana de Barcelona*), these centers have been considered 'growth centers' that should both absorb some of the service activities concentrated in the central city of Barcelona and mitigate congestion along the radial transportation axes extending from this city (see chapter 3). Additionally, real population growth (see chapter 4) also justifies the identification of Cugat del Vallès and Rubí as important centers to organize the future development of the Barcelona metropolitan region.

The measurement of polycentricity

Following the identification of centers, the metropolitan spatial structure of Barcelona was further studied in chapter 6 to explore its level of polycentricity. A polycentric configuration is analyzed using numerous criteria, including a minimum spatial balance in the distribution of urban attributes and flows, a minimum level of spatial integration and complementarity among the centers of a metropolitan area. Measuring these characteristics not only provides useful evidence-informed knowledge to support the definition of effective and feasible polycentric development strategies but also enables monitoring of their implementation.

The findings of the analyses performed in chapter 6 illustrated that although the outcomes of the measurement of these characteristics of polycentricity depend on the function (type of flow) considered, which in turn varies according to individual-level attributes, both morphological and functional polycentricity exist in the Barcelona metropolitan region. More specifically, it was revealed that this metropolitan region is more functionally than morphologically polycentric because of the stronger evidence for a more balanced distribution of flows, spatial integration, and complementarity among its centers. Given this evidence, it was argued in chapter 6 that the long-standing (since the 20th century) polycentric strategy of several spatial plans for the Barcelona metropolitan region has indeed fostered polycentricity.

Implications for planning

The outcomes of identifying centers in a metropolitan area by using an empirical method provide the makers of the plans with good insight into the spread of agglomeration economies over a metropolitan area. The finding that is the most relevant finding to the application of a polycentric development strategy in the Barcelona metropolitan region is that the polycentric territorial model of the 2010 Barcelona Metropolitan Plan is not the most accurate territorial model to attempt to realize the assumed benefits of polycentricity because some of those cities that have a high level of agglomeration economies and cast severe agglomeration shadows over their surroundings are not identified as centers. In contrast, the novel method of identifying centers proposed in chapter 5 enables both planners and policymakers to better understand the costs and the benefits of a polycentric metropolitan structure.

The information obtained from the measurement of the metropolitan spatial structure and its development informs plans' makers about the governance implications, understanding, and expectations of polycentric development. There are three findings that are the most relevant findings to the application of a polycentric development strategy. First, the stronger functional linkages among centers with regard to a variety of flows (e.g., trips for shopping, leisure, and business flows) found in chapter 6 illustrate that the Barcelona metropolitan region operates as a functional integrated entity. This finding clarifies the debate about the appropriate territorial scale upon which apply a polycentric development strategy; in addition, it makes important input about the appropriate scale on which to base a metropolitan government. It was found that achieving the (assumed) positive agglomeration externalities related to polycentric development requires the consideration of a metropolitan territory of Barcelona that corresponds to the area envisioned by the 1966 *Pla Director de l'Àrea Metropolitana de Barcelona*; however, it does not match the territory upon which several other territorial visions of Barcelona's metropolitan realm were focusing. For example, the 1976 *Pla General Metropolità de Barcelona* focused on a much narrower area based on Barcelona and 27 surrounding municipalities, and thus, it excluded centers such as Sabadell, Terrassa, Rubí, Martorell, Granollers, Mataró and Vilanova I la Geltrú; however, those centers were functionally tied to Barcelona.

Second, the study of the development of the extent of complementarity among centers improves the understanding of polycentric development in the context of Catalonia's planning practice. More specifically, it clarifies our understanding of the role played by each center in the metropolitan area when the makers of the plans (e.g., the 2010 Barcelona Metropolitan Territorial Plan) aim to establish complementary (non-hierarchical) relationships among centers to increase economic competitiveness. Based on the complementary and competitive relationships among centers identified in chapter 6, it seems that Barcelona can further develop its role as a 'Global Gateway' for global advanced producer services and highly skilled professional networks, whereas Rubí, Martorell, and Terrassa form an important cluster of high-technology industries, Sant Cugat del Vallès plays a specialist role in accountancy and business consultancy activities and El Prat de Llobregat is a center of transportation, storage, and logistics activities.

In turn, identification of these roles also provides relevant information for the elaboration of regional integration and governance policies. For instance, the design of an urban strategy aimed at organizing the development of more urbanization or localization economies in centers can increase the performance of firms that are clustered in them. This could be accomplished by developing the urban projects in a center to further strengthen the particular specialization of that center—e.g., Rubí and Martorell as a high-technology industry cluster—and by stimulating complementary interfirm networks among firms located in centers with related economic profiles—e.g., Barcelona and El Prat de Llobregat. Likewise, centers with a similar profile would benefit from further co-operation between firms, enabling sharing of both costs and opportunities—e.g., Barcelona and Cugat del Vallès.

Third, the stronger evidence for functional polycentricity compared to morphological polycentricity in Barcelona found in chapter 6 informs policymakers about which aspects of such a metropolitan spatial structure deserve more attention when their aim is to develop policies that build economic competitiveness, social equity, and environmental sustainability. More specifically, this solid evidence for functional polycentricity notes that it may be easier to foster better metropolitan performance by focusing on centers' functional aspects. For instance, the strong evidence for spatial integration among centers and the overall development of more complementary relationships among them strengthens support for a tangential model of transportation networks among centers to reduce congestion and increase the efficiency of the public transport system. Both the integration and the development of complementarity among centers are prerequisites for encouraging individuals' flows among and to centers and thus, for justifying investments in transport networks aimed at reducing interaction constraints both among centers and between centers and their neighboring areas. To explore whether planning policies (either those discussed above or others) are effective, is important to analyze the extent to which individuals respond. In this regard, an understanding of the extent to which individuals' travel and activity behaviors are influenced by agglomeration benefits in a polycentric spatial structure—as the answers to the third general question of this thesis make clear—holds the key to drawing conclusions about the effectiveness/feasibility of planning policies that are built upon the effects of polycentricity.

Conclusion

A better integration between the literatures on the conceptualization of polycentricity potentially informs spatial plans about the effectiveness and feasibility of polycentric development strategies. This integration revealed which method (empirical or non-empirical) of identifying centers most accurately defines the polycentric model in the Barcelona metropolitan region, which is an essential step in empirically substantiating the link between polycentricity and performance in a metropolitan area because differences in the identification of centers could lead to different conclusions on the understanding of the costs and benefits of a polycentric metropolitan structure. The main advantage of the novel method of identifying centers that is proposed and tested here is that it considers the various pathways through which centers may emerge, namely, the decentralization and the incorporation-fusion trajectories. This method was better able to identify as centers those cities that have the highest level of agglomeration economies and cast the most severe agglomeration shadows over their surroundings.

In addition, the incorporation of the functional and morphological dimensions of polycentricity—as traditionally coined by the inter-urban polycentricity literature—into the measurement of the degree of polycentricity on the intra-urban scale has contributed to building more sound arguments either for or against supporting a polycentric development strategy in a metropolitan area. Additionally, it has provided planners with valuable insights into not only how to address issues related to the understanding, governance implications, and expectations of polycentric development but also how to monitor the implementation of a polycentric development strategy.

To what extent does polycentricity foster better performance in a metropolitan area, and how can its effects be realized in planning practice?

Chapters 7 and 8 presented the research findings related to the research question set forth above. Both chapters considered three distinct dimensions of a polycentric spatial configuration that play a role in the development of agglomeration benefits in a metropolitan area to build a more comprehensive, systematic empirical framework that attempts to unify the fragmented empirical research on the advantages of polycentricity and therefore, to achieve broader conclusions about polycentricity's effects. These dimensions include the following: (1) the size of centers, (2) the (geographic) proximity to centers, and (3) the aggregate size of centers through their integration. Whereas the relationships between polycentricity and the co-location of jobs, urban amenities and households, along with people's choice of travel mode were largely discussed in chapter 7, chapter 8 studied the effects of polycentricity on travel behavior externalities. The latter were expressed in trip distances, travel times and per capita CO_2 emissions attributable to transportation. Moreover, the research findings in these chapters provided valuable insights into how the benefits of polycentricity can be realized in planning practice.

Polycentricity and travel mode choice

Chapter 7's empirical analysis of people's choice of travel mode showed that together with individual-level characteristics, a polycentric structure is a relevant determinant that affects individuals' travel mode choices for both work- and non-work-related trips. In contrast, built environment attributes have generally modest effects on travel mode choice, although the findings also revealed that these effects differ depending on which dimension of the polycentric metropolitan structure was studied: (1) being located in or oriented toward centers (which type of city), (2) being located close to these centers (the distance to centers), and (3) interaction patterns among centers (which type of interaction). As chapter 7 argued, that finding empirically substantiated the proposition people's choice of travel has become more dependent on the metropolitan structure and in particular, on the existence of a polycentric pattern.

The findings of the multilevel multinomial logit models explaining the probability of using public transportation or bicycling-walking instead of private transportation also indicated that the type of interaction (i.e., between different categories of places: central city, secondary centers, centers' neighboring areas, and peripheral areas) and the type of city (i.e., which size have these four aforementioned categories) are strong determinants of travel mode choice; they are even stronger than the strongest predictors at the individual-level (car ownership and professional status) and the built environment attributes (land-use mix and the presence of urban amenities). This was not the case for the effects of proximity to centers; nevertheless, the distance of a place to centers (excluding the central city, i.e., secondary centers) appeared to be a stronger factor in determining travel mode choice than most of the trip maker's individual characteristics and all of the built environment's attributes when non-work-related travel is considered, particularly with respect to education and shopping.

Polycentricity and travel behavior externalities

The various empirical analyses performed in chapter 8 (multilevel structural equation models, Empirical Bayes predictions, and random intercept models) illustrated that a polycentric metropolitan structure is significantly and positively associated with shorter trip distances, shorter travel times, and lower transportation-related CO_2 emissions for both work- and non-work-related travel. Moreover, the findings of chapter 8 indicated that the distance to centers and the size of centers exerted a considerable effect on these three negative travel behavior externalities. Whereas the magnitude of the net effects of polycentricity appeared to be moderate and as large as individual-level determinants when the effects of being located close to centers were considered, the net elasticities of polycentricity were considerably higher when the effects of being located in or oriented toward centers were considered, particularly with respect to non-work-related travel.

The findings that resulted from estimating multilevel structural equation models to explain the causes of greater negative travel behavior externalities also showed that it was important to consider the composite (direct: active and indirect: passive) effects of polycentricity operating through individual-level or built environment attributes to avoid underestimating polycentricity's total effects. Whereas the significant indirect effects of being located close to centers represented at least 18-20% of the total effects, the significant indirect effects of being located in or oriented toward centers accounted for at least 17-40% of the total effects. As argued in chapter 8, that finding also empirically substantiated the proposition that negative travel externalities were becoming more closely connected to the metropolitan structure because built environment attributes (e.g., job density and the job-housing ratio) and certain individual-level characteristics (e.g., the availability of private transport) were being influenced by the existence of multiple centers in a metropolitan area. More precisely, the finding that polycentricity actively and passively affected travel behavior externalities clarified that the greater the proximity of residential areas to centers, the higher the employment density and the job-housing ratio and the lower the availability of private transport to their residents. In turn, that resulted in a greater benefit for the residents of locations close to centers because the greater the compactness and the proximity between economic and residential functions and the lower the availability of private transport, the shorter the travel times and trip distance and consequently, the lower the transport-related CO_2 emissions. Of course, the results of considering polycentricity's composite effects also indicated that these benefits were even larger for the residents of centers themselves.

Polycentricity and the co-location of jobs, people, and urban functions

Consistent with the aforementioned findings, chapter 7's descriptive analysis noted that the polycentric development in Barcelona since 1991 has allowed the co-location of people, jobs, and urban functions, leading to shorter trip lengths and durations. Most residents of centers performed their daily activities either in or close to these centers. Additionally, most centers' jobs and urban functions were filled and used either by their own residents or by people living nearby. These travel patterns were translated, as chapter 7 found, into shorter average trip distances and trip times for residents of centers (central city and secondary centers). Moreover, these mobility patterns noted what has been empirically substantiated by the findings of chapter 8. The effects of proximity to centers also helped achieve more balanced trip lengths and durations. Residents of centers' neighboring areas (municipalities adjacent to centers), as shown by the descriptive analysis of chapter 7, experience increasingly shorter average trip distances and times than residents of areas further away from centers (peripheral areas).

Costs in a polycentric metropolitan structure

The research findings of chapter 8 highlighted that the roles played by congestion and centers' capacity to attract people living further away leads to increased trip distance, trip time and transportation-related CO_2 emissions. More specifically, the estimated multilevel structural equation models and random intercept models indicated that the closer individuals lives to the central city of Barcelona, the higher the likelihood of longer-duration trips because of the presence of congestion along the radial transportation axes towards the central city. Additionally, the Empirical Bayes predictions shown in chapter 8 confirmed the role played by congestion in the Barcelona metropolitan region. Those predictions illustrated that travel times for centers located close to the radial transportation axes oriented toward the central city of Barcelona were negatively affected by congestion (e.g., L'Hospitalet de Llobregat).

When incorporating the dimension of the interaction patterns among centers (i.e., exploring whether interaction among the various categories of places—central city, secondary centers, centers' neighboring areas, and peripheral areas—leads to different travel behavior externalities) in the random intercept models, it was found that trips to centers from more-distant areas (i.e., peripheral areas) were particularly likely to greater negative travel behavior externalities for both work- and non-work-related travel. In contrast, interactions among centers led to shorter trip distances, shorter trip times and lower transportation-related CO_2 emissions compared to interactions among peripheral areas. Additionally, the effects of interactions among centers reduced travel behavior externalities more than the effects of proximity to centers (central city and secondary centers). However, interactions between a non-center place and a center fostered greater negative travel behavior externalities.

Conclusion

A polycentric metropolitan structure exerts a considerable influence—both active and passive—on enhancing performance in a metropolitan area through individuals' travel behavior. The effects of polycentricity—i.e., (1) of being located in or oriented toward centers, (2) of being located close to centers, and (3) of interaction patterns among centers—appear to be generally larger than the effects of individual-specific characteristics (i.e., sociodemographic characteristics and travel-related attitudes) and built environment attributes with respect to encouraging people to use more intensely sustainable mode choices (public transit and non-motorized modes) and reducing travel behavior externalities (i.e., trip distance, trip time, and transportation-related CO_2 emissions). More specifically, the most important dimension of a polycentric metropolitan structure in fostering a more sustainable mobility pattern is generally the type of interaction, followed by the type of city, which in turn is more important than the distance to centers.

Based on these effects, polycentric development fosters better performance in the Barcelona metropolitan region because it has influenced individuals' travel behavior through three different dimensions. First, people living in centers or doing their daily activities in these centers use more public transit or slow modes, and their trips are shorter, take less time, and cause less transportation-related CO_2 emissions than if they do not live in centers or are not carrying out their activities in these centers. Second, people living close to centers exhibit a more sustainable pattern of travel behavior than those living further away. Third, people traveling among centers are more likely to use public transportation, to experience shorter-length or -duration trips and to make greater reductions in the environmental impact of their travel than people traveling among peripheral areas. In short, agglomeration benefits in a polycentric metropolitan region explain these three aforementioned findings. Therefore, the translation of the benefits of polycentricity into planning policies requires the simultaneous consideration of (1) the size of centers, (2) the size of and proximity to centers, and (3) the size of and interaction among centers.

§ 9.3 Evidence-informed guidelines for planning policies

The estimated effects of polycentricity (e.g., average marginal effects and total, direct, and indirect elasticities) found in chapters 7 and 8 lead to a set of policy recommendations on urban and transportation developments that will enhance the performance of the Barcelona metropolitan region. These policies aim to inform the plans' makers about how the benefits of polycentricity can be realized in planning practice, therefore provide them with an improved understanding of polycentric development to more effectively fulfill spatial plans' economic, social, and environmental objectives.

Essentially, the translation of the benefits of polycentricity into evidence-informed guidelines for planning policies requires the consideration of the various dimensions of a polycentric spatial structure that play a role in the development of agglomeration benefits in a metropolitan area: (1) the size of centers, (2) the proximity to centers, and (3) the aggregate size of centers through their integration. The consideration of these dimensions—along with related policy recommendations to improve the effectiveness of the 2010 Barcelona Metropolitan Territorial Plan's objectives in terms of individuals' travel behavior (see Figure 4.1 in chapter 4)—is shown in Figure 9.1. It is important to note that Figure 9.1 sorts the three abovementioned dimensions of a polycentric spatial structure according to their importance to foster better performance in a metropolitan area.

Aggregate size of centers through their integration

Four main policy guidelines can be established to realize the benefits of a polycentric metropolitan structure associated with the aggregate size of centers through their integration. First, it is important to support new, more efficient public transportation networks among centers to allow those centers to better exploit their aggregate urban size, leading to a greater development of agglomeration economies. Illustrative examples include prioritizing infrastructure investments both on the R9 rail line—an orbital rail line that connects secondary centers (Vilanova I la Geltrú, Martorell, Sant Cugat del Vallès, Rubí, Terrassa, Sabadell, Granollers, and Mataró)—and in other public transportation networks (rail or metro) aimed at connecting the central city of Barcelona with secondary centers—e.g., Sant Cugat del Vallès (R3 rail line) and El Prat de Llobregat (L2-L9 metro lines).

Second, it is important to enhance the complementarity among centers on the metropolitan scale in terms of economic sectors, occupations, and urban functions through promoting compact-city/transit-oriented development. This policy guideline demands that policymakers focus on the urban design of these developments to boost the positive effects of integration among centers. That requires the identification of which types of economic activity, urban amenities and residents (their occupational profile) are the most suitable for each new compact-city/transit-oriented area in existing centers. One tip for policymakers is to use the role of centers identified by measuring the level of functional polycentricity and more specifically, by examining the complementarity relationships among centers.

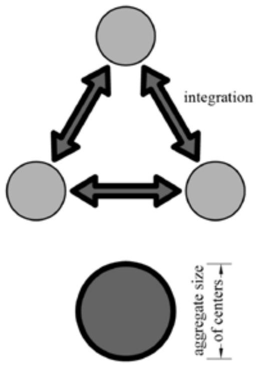
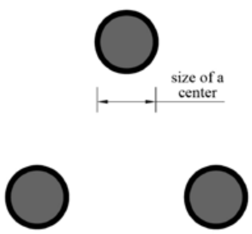
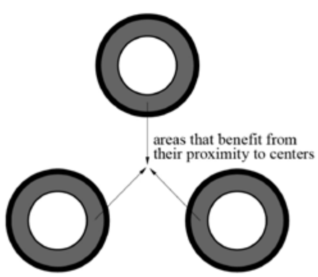
Dimension of a polycentric spatial structure	Policy guidelines based on the estimated effects of polycentricity
A) Aggregate size of centers through their integration 	1. Support new, more efficient public transportation networks among centers to allow those centers to better exploit their aggregate urban size, leading to a greater development of agglomeration economies. 2. Enhance the complementarity among centers on the metropolitan scale in terms of economic sectors, occupations, and urban functions through promoting compact-city/transit-oriented development. 3. Support new, more efficient public transportation networks between centers and their neighboring areas to stimulate interactions toward centers and increase nearby residents' access to the agglomeration benefits of centers that are integrated with their nearest center. 4. Support new, more efficient road networks among secondary centers to mitigate congestion along the radial transportation axes oriented toward the central city of Barcelona.
B) Size of centers 	5. Promote compact-city/transit-oriented development in existing centers (central city and secondary centers) to encourage more residents of centers to access their agglomeration benefits.
C) Proximity to centers 	6. Promote compact-city/transit-oriented development in larger places near centers to allow more residents of these centers' neighboring areas to benefit from their proximity to the agglomeration benefits of one or more centers. 7. Limit growth in areas located further away from centers both to mitigate (as much as possible) the high travel costs (trip distance and time) incurred by the residents of these peripheral areas and to decrease the transportation-related CO_2 emissions that they cause.

FIGURE 9.1 Translation of the benefits of polycentricity into policy guidelines

Note(s): these three distinct dimensions of a polycentric metropolitan structure are sorted according to their importance in fostering better performance in a metropolitan area. More specifically, the effects of interaction patterns among centers are generally the most important for encouraging people both to use sustainable travel modes and to reduce their trip time, trip distance, and transportation-related CO_2 emissions.

Third, it is important to support new, more efficient public transportation networks between centers and their neighboring areas to stimulate interactions toward centers and increase nearby residents' access to the agglomeration benefits of centers that are integrated with their nearest center. Illustrative examples include prioritizing infrastructure investments in the S1 and S2 rail lines (which link Terrassa and Sabadell, respectively, with their neighboring areas) and the TV9 tram line (which improves the connectivity of Granollers with its surrounding areas oriented toward Sabadell).

Fourth, it is important to support new, more efficient road networks among secondary centers to mitigate congestion along the radial transportation axes oriented toward the central city of Barcelona. One key example is to prioritize development of the Ronda del Vallès, an orbital road around the central city of Barcelona that enhances connectivity among secondary centers.

Size of centers

One main policy guideline can be provided to policymakers to address the benefits of a polycentric metropolitan structure related to the size of centers. That guideline is to promote compact-city/transit-oriented development in existing centers (central city and secondary centers) to encourage more residents of centers to access their agglomeration benefits. One key example is to promote the concentration of new developments based on increasing density (residential and economic activities), land-use mix, and the presence of urban amenities in the developable land of close-by secondary centers (Sant Cugat del Vallès, Rubí, Terrassa, Sabadell, and Granollers), preferably around public transportation stations (e.g., Rubí Nord, Sabadell Nord, and Granollers-Sud). One idea is for policymakers to define some of these new developments by allocating distinct economic activities and urban functions to encourage more residents of centers to access not only the agglomeration benefits of their center (center which they live) but also the agglomeration benefits of other centers.

Proximity to centers

Two main policy guidelines can be suggested to realize the benefits of a polycentric metropolitan structure that are associated with the proximity to centers. First, promote compact-city/transit-oriented development in larger places near centers to allow more residents of these centers' neighboring areas to benefit from their proximity to the agglomeration benefits of one or more centers. Illustrative examples include supporting developments in Cerdanyola del Vallès, Montcada I Reixac, Santa Perpètua de Mogoda and Barberà del Vallès because of their substantial reserves of developed land, their close proximity to various centers, and their ability to integrate new urban developments with anticipated investments in public transportation (e.g., Cerdanyola Universitat and Parc Tecnològic rail stations). Another idea for policymakers to prioritize developments close to centers is that the closer these developments are to the central city of Barcelona, the greater the travel time experienced by the residents of these new developed areas because of the presence of congestion along the radial transportation axes towards Barcelona. This idea indicates that new urban developments in the centers' neighboring areas of Sant Boi de Llobregat and Santa Coloma de Gramenet might be less convenient.

Second, it is important to limit growth in areas located further away from centers both to mitigate (as much as possible) the high travel costs (trip distance and time) incurred by the residents of these peripheral areas and to decrease the transportation-related CO_2 emissions that they cause when they want to access centers' agglomeration economies.

§ 9.4 Agenda for research and policy

Having answered the general research questions of this dissertation and presented its planning policy recommendations, this final section presents an agenda for research and policy related to the multiple relationships among polycentricity, performance, and planning in metropolitan regions. This agenda arises out of the range of challenges and research gaps discussed in chapter 2 that this thesis could not cover in their entirety. In addition, the research raised new questions. This agenda refers both to the Barcelona metropolitan region case and to more general advances that are needed in the reciprocal relationships among polycentricity, performance and planning.

Linking polycentricity-performance to planning

The focus on individuals' travel behavior in this thesis's empirical analyses needs to be extended to achieve broader conclusions about the effects of polycentricity on the performance of the Barcelona metropolitan region. Moreover, this thesis's empirical analyses must be extended to elaborate more comprehensive guidelines for planning policies that address all of the planning objectives of the 2010 Barcelona Metropolitan Territorial Plan. Two research perspectives can be distinguished to address these two demands for further research.

First, the object of analysis could be extended from people to firms and their spatial behavior. Second, a wider range of externalities could be considered (see section 2.3 in chapter 2). Of particular interest would be further research into the link between polycentricity and other indicators of performance such as labor productivity, unemployment, housing and land prices, income per capita, household-related CO_2 emissions, and land consumption. For instance, further research into the link between polycentricity and housing prices can reveal the extent to which housing prices are higher in centers compared to other type of cities and the extent to which this agglomeration cost is attenuated with distance from centers. These findings can easily be used to elaborate social housing policies aimed at compensating low-household incomes for high housing prices while they continue to enjoy the agglomeration benefits in a polycentric metropolitan area because of the location of affordable housing both in centers and in their surrounding areas.

More research into the relationship between polycentricity and performance is also opportune when better and more-detailed data become available to elaborate more comprehensive planning policies. For example, the multilevel structural equation models estimated in chapter 8 could not include individuals' residential-related attitudes and all of the factors identified by the theory of planned behavior because of the research design of the travel survey data on which the analysis was grounded.

One of the general research goal of this thesis has been to empirically substantiate the relationship between polycentricity and performance on the metropolitan scale, considering the Barcelona metropolitan region. Chapter 2 was proposed a conceptual framework to enable a broad test of the effects of polycentricity. Further research is required in other metropolitan areas to provide new insight into the relationship between polycentricity and performance by focusing on individuals' travel behavior and on the other indicators of performance mentioned above. It would be preferable to conduct multiple-case study research that would examine the effects of polycentricity on metropolitan performance by considering (1) the size of centers, (2) the (geographic) proximity to centers, and (3) the aggregate size of centers through their integration.

Another theme of particular interest for further research is the question of the extent to which metropolitan areas' better performance is more closely associated either with their spatial organization—i.e., with polycentricity—or with other factors at a higher level—i.e., quality of governance and domestic and cross-border economic trends and policies (e.g., foreign direct investment and research and development expenditures). Answering this question will provide valuable insights into the true relevance of polycentricity to building economic competitiveness, social equity, and environmental sustainability in metropolitan areas through planning policies.

The link between polycentricity and planning

In terms of the relationship between polycentricity and planning, three important issues rise. First, there is an issue related to how to address the governance implications that are derived from the application of a polycentric development strategy in metropolitan areas, as discussed in chapter 2 (section 2.4). In general, the governance implications of polycentric development indicate a need for further research into the gap between plan and practice: achieving the desired objectives associated with polycentric development is not only determined by providing the appropriate research evidence to elaborate policies but also depends on the implementation of polycentric development when the political dimension plays a significant role. Accordingly, it would be particularly interesting to conduct qualitative research aimed at questioning whether the available planning instruments to plan metropolitan areas (e.g., the 2010 Barcelona Metropolitan Territorial Plan and its sub-plans such as the ongoing Urban Director Plan for planning Barcelona and its surrounding municipalities) are sufficiently effective and efficient to implement a polycentric development strategy.

Second, the challenging question about the extent to which the urban structure of a metropolitan area is at all modifiable through development policies such as spatial plans. In particular, is it feasible to stimulate the development of 'new centers' when in reality, there few dynamics suggest a development in that direction? In the past, planners assumed that significant changes in the urban structure of metropolitan areas are propitious for the implementation of policies aimed at economic and social developments (see, e.g., the 1966/1974 *Pla Director de l'Àrea Metropolitana de Barcelona*). However, other planners have argued that the urban structure is a long-term process whose initial shape largely determines or constrains the possibilities of shifting the development of the urban structure. This dissertation showed that the spatial restructuring of Barcelona itself should be considered a long-term process, whereas the development of centers (e.g., Sant Cugat del Vallès) linked to new infrastructure improvements appear to be either a medium- or a short-term process. Therefore, additional empirical research on understanding the causes of the dynamics of the urban structure in metropolitan areas would be desirable to shed more light on the feasibility of planning policies aimed at stimulating 'new centers'. A good starting point to address this question would be to empirically explore the causes for the co-location of jobs, urban functions, and households in a polycentric metropolitan area. It is necessary to gain an understanding of whether people follow jobs and urban functions or whether jobs and urban functions follow people.

Third, novel research arises from establishing a link between polycentric development and other planning concepts and more specifically, from considering transit-oriented development as the planning instrument to realize the benefits of polycentricity. In this dissertation, it was shown that the effects of the built environment on travel behavior vary depending on which dimension of a polycentric metropolitan structure was studied, suggesting that individuals' travel behavior was becoming more dependent on the existence of a polycentric pattern. That finding illustrates that planning concepts, which consider the sustainability effects of the built environment to create a bridge between *sustainable development* (broadly interpreted as fulfilling economic, social, and environmental objectives) and territorial development, will be influenced by polycentricity because polycentricity exerts an indirect impact on them through the built environment. Therefore, it would be particularly interesting to perform additional research aimed at empirically substantiating whether and to what extent the economic, social, and environmental advantages of transit-oriented development depend on the effects of polycentricity and if so, how the concept of transit-oriented development can be embedded in a polycentric development strategy to realize the benefits of polycentricity in planning practice. The outcomes of this research may be of interest to the makers of those spatial plans—e.g., the 2013 Plan Bay Area (San Francisco), the 2014 Plan for Growing Sydney, and the 2013 Copenhagen Fingerplan (see Table 1.1 in chapter 1)—who have advocated for transit-oriented development as the best development strategy to achieve the objectives of a spatial plan.

The conceptualization of polycentricity

This thesis has proposed a novel method of identifying centers that not only takes into account the specific development trajectory of a center but also departs from a novel conceptualization of centers as being areas that have the most agglomeration benefits and that cast the most severe agglomeration shadows over their surroundings. Although this method was positively tested against other methods for the Barcelona metropolitan area, it must also to be tested for other metropolitan areas to obtain wider validity. Perhaps this is most important for metropolitan areas in which a polycentric development strategy is being implemented (see Table 1.1 in chapter 1)

More novelties are to be expected from the further integration of the relatively distinct literatures on intra- and inter-urban polycentricity. Although this thesis has taken steps in that direction, it seems important to recommend that the inter-urban polycentricity literature pay more attention to the identification of centers, which is a prominent issue in the intra-urban polycentricity literature and allows for a better exploration of the link between polycentricity and performance. Therefore, the empirical identification of centers in polycentric urban regions (e.g., the Randstad and the Rhein-Ruhr) could allow scholars to examine the effects of inter-urban polycentricity on performance in a more comprehensive manner and perhaps to provide new insights into why the literature has found inconclusive effects of polycentricity on the inter-urban territorial scale (see Burger et al., 2014a; Meijers, 2008; Schwanen et al., 2003, 2004).

The possible contribution of what has become known as 'Big Data' also deserves further research because it is potentially relevant to our understanding of polycentric development. Whereas traditional datasets such as census data furnish a high degree of reliability and representativeness of the spatial distribution of activities in metropolitan areas, they are collected only once each (long) time period. New sources of data such as Big Data add rich spatial-temporal information on the spatial organization of activities (see Reades et al., 2009; Sevtsuk and Ratti, 2010). This might allow these new data sources to better depict the metropolitan spatial structure's complexity and its change over the course of much shorter periods (e.g., a week and a year). Nevertheless, such claims still must be empirically justified.

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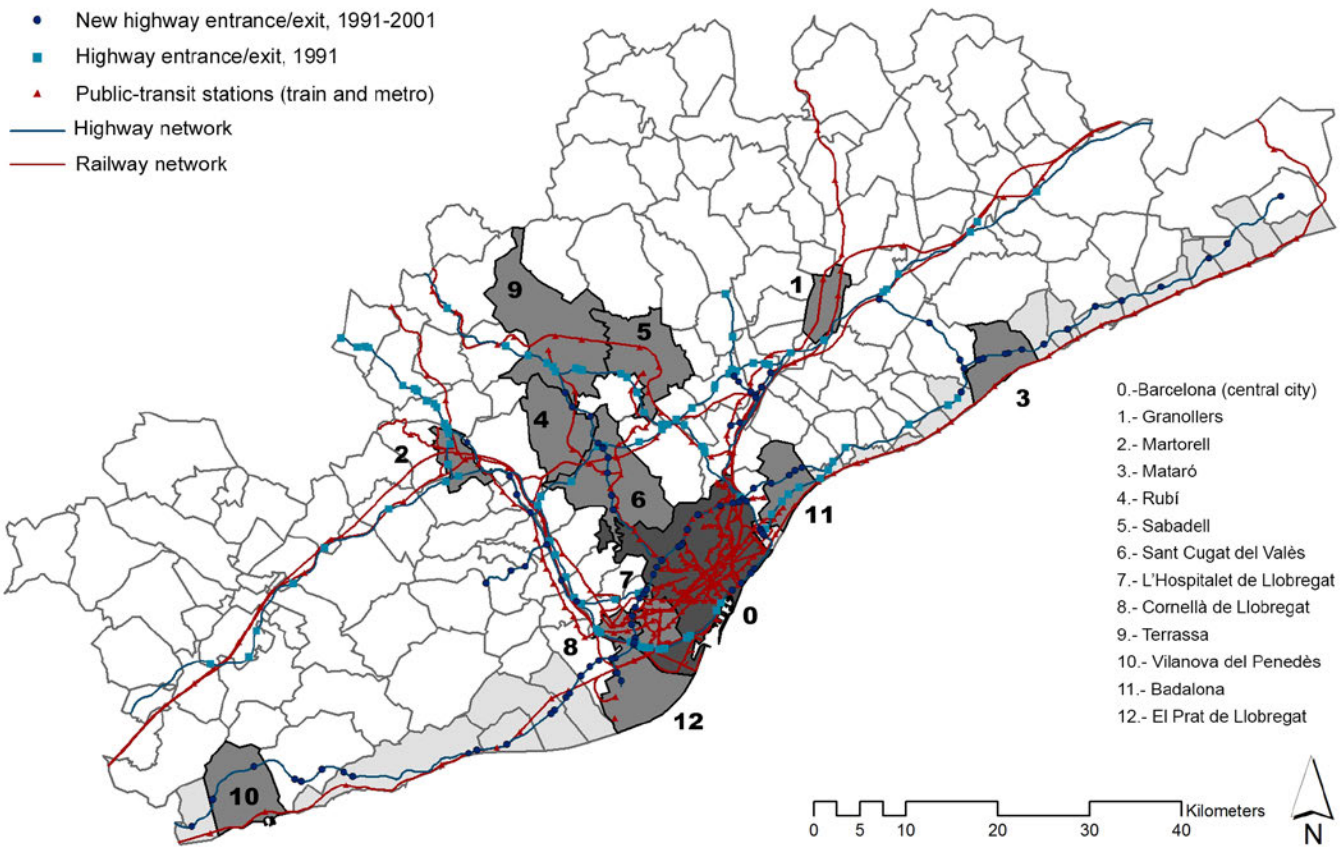
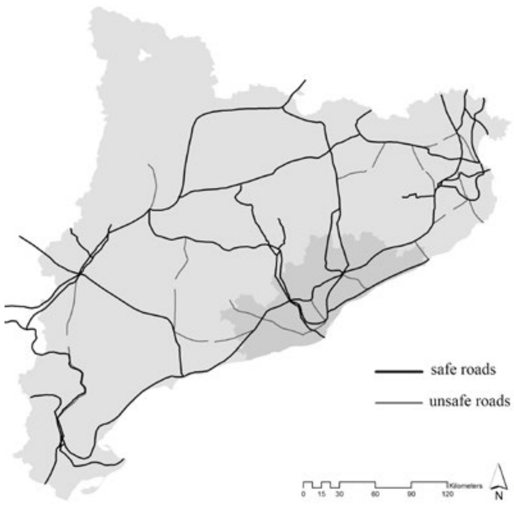
Appendices chapter 5

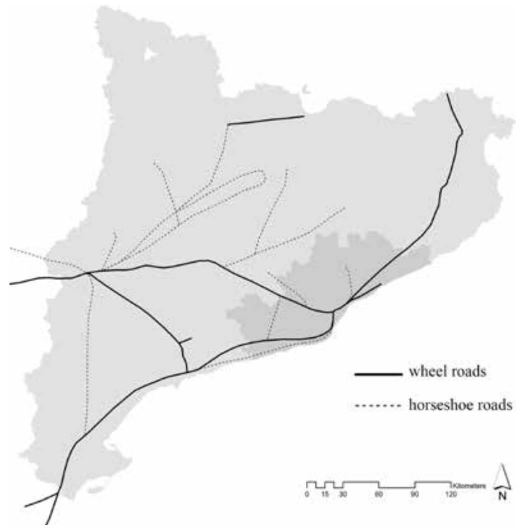


APPENDIX 5.1 Polycentricity in Barcelona: centers and infrastructure

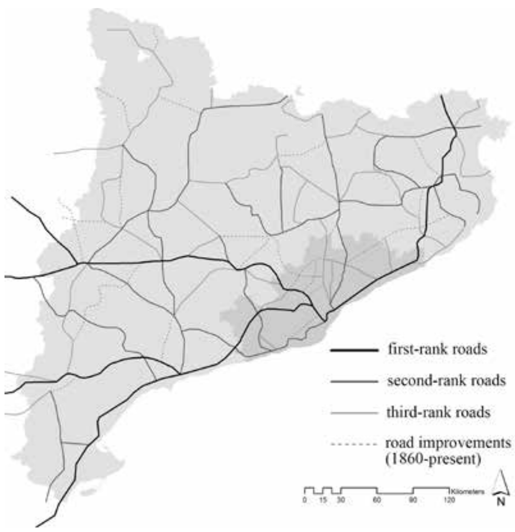
Note(s): data for transportation networks come from the Catalan government's Department of Territorial Policy and Public Works (DPTOP).



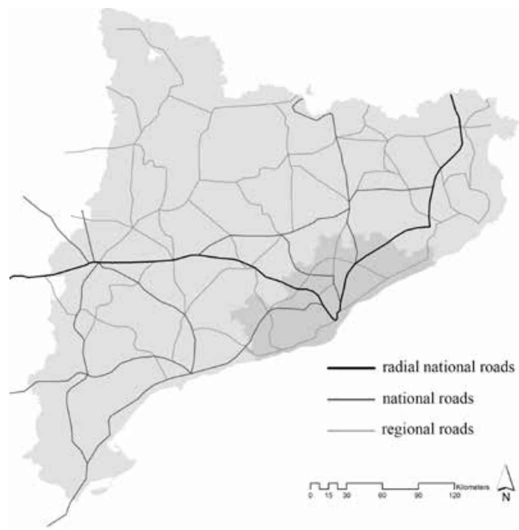
A *Roman roads*



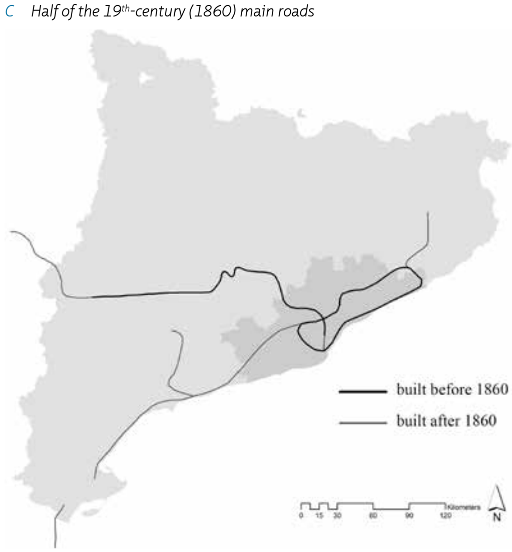
B *Postal roads, 1760*



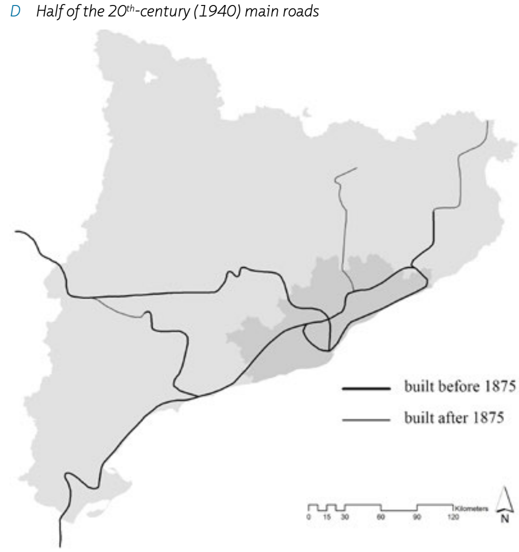
C *Half of the 19th-century (1860) main roads*



D *Half of the 20th-century (1940) main roads*



E *Railroad network, 1865*



F *Railroad network, 1880*

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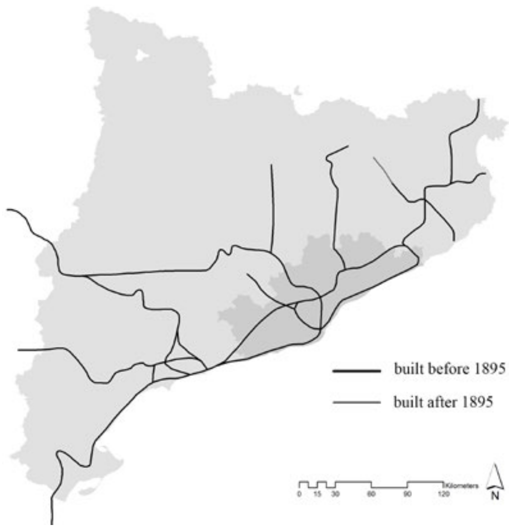
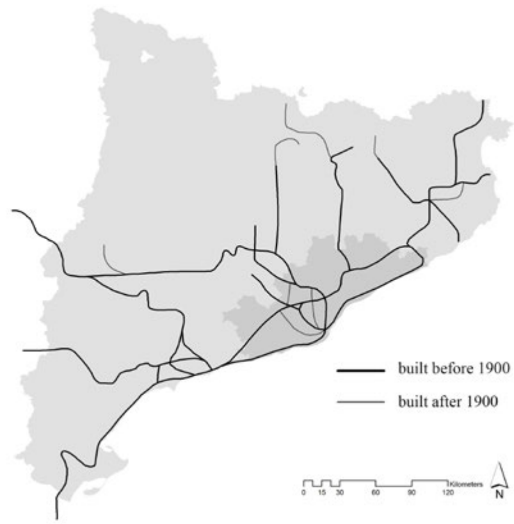
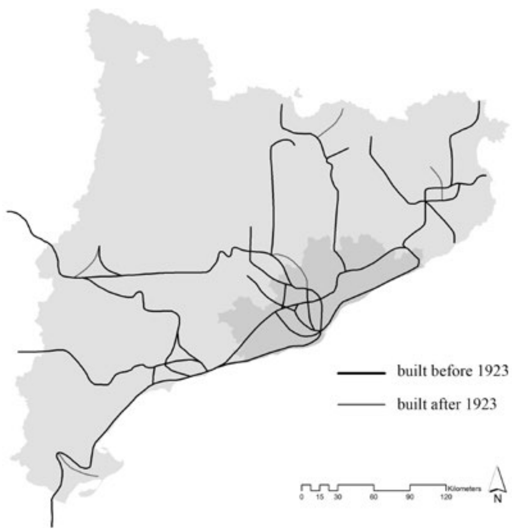


G Railroad network, 1900



H Railroad network, 1923



I Railroad network, 1935

APPENDIX 5.2 Evolution of transportation infrastructures (roads and railroad network) in Catalonia: historical instrumental variables

Source: own elaboration based on Soto and Carreras (2006-7) and the Instituto Geográfico Nacional de España (IGN, 2008).

Appendices chapter 6

SECTORAL-BASED CLASSIFICATION AT THE 2-3 DIGIT LEVEL (CCAE93 REV.1): 5 MAIN SECTORAL GROUPS AND 28 INDIVIDUAL SECTORS		
High-technology industries (HTI)	30	Manufacture of office, accounting and computing machinery
	32	Manufacture of radio, television and communication equipment and apparatus
	33	Manufacture of medical, prevision and optical instruments, watches and clocks
	244	Manufacture of pharmaceutical products
	353	Manufacture of aircraft and space craft
Finance, insurance and real estate (FIRE)	65	Financial intermediation, except insurance and pension funding
	66	Insurance and pension funding, except compulsory social security
	67	Activities auxiliary to financial intermediation
	70	Real estate activities
Knowledge-intensive services (KIS)	64	Post and telecommunications
	72	Computer and related activities
	73	Research and development
	80	Education
	85	Health and social work
Advanced producer services (APS)	741	Legal, accounting, book-keeping and auditing activities; tax consultancy; market research and public opinion polling; business and management consultancy
	743	Technical test and analysis
	745	Staff selection
	746	Security and investigation services
	747	Industrial cleaning activities
	742	Architectural and engineering activities and other technical activities
	744	Advertising
	748	Other producer services
Creative industries (CI)	221	Publishing
	222_223	Graphic arts and related service activities and reproduction of recorded media
	921_924	Motion picture and video activities and news agency activities
	922	Radio and television activities
	923	Artistic and recreational activities
	925	Library, archives, museums and cultural activities

APPENDIX 6.1 Sectoral-based classification: knowledge-based sectors

OCCUPATIONAL-BASED CLASSIFICATION AT THE 2 DIGIT LEVEL (CCO94): 8 MAIN OCCUPATIONAL GROUPS AND 22 INDIVIDUAL OCCUPATIONS		
Management	10	Chief executives, senior officials and legislators
	11	Business chief executives
	12_15	Managers in wholesale and retail trade business
	13_16	Managers in hotels and restaurants business
	14_17	Managers in other business
Professional: business professionals	33	Business and trade associate professionals
	34	Business management professionals
Professional: science and engineering professionals	20	Professionals in physical, chemical, mathematical and engineering sciences with a 4-5 year college degree
	21	Professionals in natural sciences and health with a 4-5 year college degree
	26	Professionals in physical, chemical, mathematical and engineering sciences with a 3-year college degree
Technical: science-technical occupations	30	Physical, chemical and engineering technicians
	32	Education, flight instructors, navigation and driving vehicles technicians
	40	Accounting, financial and other related services technicians
Professional: health professionals	27	Professionals in natural sciences and health with a 3-year college degree, except opticians, physiotherapists and similar
Technical: other health occupations	31	Natural sciences and health technicians
	35	Other assistant technicians
Professional: education, law and social science-related professionals	22	Professionals in education with a 4-5 year college degree
	23	Professionals in law
	24	Professionals in business organization and professionals in social and human sciences with a 4-5 year college degree
	28	Professionals in education with a 3-year college degree
	29	Other professionals with a 3-year college degree
Professionals: arts and culture professionals	25	Writing, creative and performing artists, and other professionals with a 4-5 year (or similar) college degree

APPENDIX 6.2 Occupational-based classification: knowledge-based occupations

Appendices chapter 8

RANDOM INTERCEPT MODELS DETERMINANTS OF TRIP DISTANCE	WORK-RELATED TRAVEL				NON-WORK-RELATED TRAVEL			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 1	MODEL 2	MODEL 3	MODEL 4
	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]
Fixed part								
Level 1 Individual-specific characteristics								
Gender (reference = male)	-0.1787***	-0.1782***	-0.1753***	-0.0720***	-0.0376	-0.0376	-0.0211	-0.0168
Age cohorts								
36-45 years (reference)								
16-25 years	-0.1112**	-0.1121**	-0.0783*	-0.0113	0.2576***	0.2597***	0.2150***	0.0800**
26-35 years	-0.0503	-0.0482	-0.237	-0.0047	0.0765	0.0767	0.0907*	0.0456
46-55 years	-0.0675	-0.0702	-0.0509	0.0107	0.0162	0.0183	0.0070	0.0005
56-65 years	0.0102	0.0099	0.0298	0.0867*	0.0664	0.0702	0.0707	0.0339
65+ years	-0.0701	-0.0750	-0.1609	-0.0925	0.0435	0.0455	0.0595	0.0586
Household attributes								
nº of household members	0.0370**	0.0368**	0.0382**	0.0082	0.0511***	0.0506***	0.0372**	0.0017
nº of children (4- years)	0.0278*	0.0264*	0.0232*	0.0085	-0.0617***	-0.0618***	-0.0486***	-0.0278***
nº of teenagers (4-16 years)	-0.0172	-0.0163	-0.0147	0.0025	-0.0322**	-0.0312*	-0.0112	0.0105
Professional status								
Unemployed (reference)								
Business owner	-0.1163	-0.1234*	-0.0772	-0.0056	0.0393	0.0396	-0.0112	0.0132
Corporate member	0.1489	0.1426	0.2237	0.2474*	-0.4442	-0.4349	-0.4593	-0.1929
Family business	-0.1350	-0.1319	-0.0438	0.1128	0.3973	0.4001	0.5179**	0.5791***
Full-time worker	-0.0038	-0.0067	0.0267	0.0757*	0.0737	0.0726	0.0648	0.0799**
Part-time worker	-0.0266	-0.0288	0.0414	0.0719	0.0207	0.0196	-0.0390	0.0737
Others	0.1218	0.1165	0.1065	0.1698	0.0371	0.0456	0.0344	0.0597
Educational level								
Low (reference)								
Medium	0.1254***	0.1243***	0.1038***	0.037	0.1884***	0.1923***	0.1009***	0.0228
High	0.2439***	0.2448***	0.2006***	0.0894***	0.2880***	0.2903***	0.1440***	0.0151
Driver's license (reference = no license)	0.0247	0.0241	0.0105	0.0273	0.0695*	0.0694*	0.0359	0.0292
Car ownership (reference = no car)	0.0669	0.0664	0.1088***	0.0274	0.0920**	0.0912**	0.1327***	0.0663**
Motorcycle license (reference = no license)	0.0007	-0.0001	-0.0141	0.0162	0.0627	0.0632	0.0637	0.0037
Motorcycle ownership (reference = no motorcycle)	-0.0678	-0.0694	-0.0692	-0.0285	-0.1182*	-0.1168*	-0.1017	-0.0577
Level 2 Built environment attributes								
Employment density	-0.0552				-0.0651*			
Land-use mix	-0.0811**				-0.0008			
Job-housing ratio	-0.0629**				-0.0128			
Distance to the nearest public-transit station	0.0602*				0.0249			
Δ Distance to the nearest highway entrance/exit (infrastructure improvements 1991-2001)	0.0266				-0.1275***			
Presence of urban amenities	-0.2040***				-0.1737***			
Distance to the coast	-0.0170				0.0608			

APPENDIX 8.1 Multilevel regression models of trip distance: estimation results for work- and non-work-related travel

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RANDOM INTERCEPT MODELS DETERMINANTS OF TRIP DISTANCE	WORK-RELATED TRAVEL				NON-WORK-RELATED TRAVEL			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 1	MODEL 2	MDOEL 3	MODEL 4
	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]
Level 2 Polycentricity: proximity to centers								
Distance to Barcelona (central city)		0.1549***				0.1968***		
Distance to the nearest secondary center (inverse)		-0.0887***				-0.0661**		
Level 2 Polycentricity: size of centers								
Origin: peripheral areas (reference)								
Origin: central city (Barcelona)			-1.359***				-2.0613***	
Origin: secondary centers			-0.9321***				-1.2015***	
Origin: centers' neighboring areas			-0.6130***				-0.8369***	
Destination: peripheral areas (reference)								
Destination: central city (Barcelona)			0.9427***				1.7549***	
Destination: secondary centers			0.8104***				0.9923***	
Destination: centers' neighboring areas			0.4829***				0.7295***	
Level 2 Polycentricity: aggregate size of centers through their integration								
Peripheral areas to peripheral areas (reference)								
Central city to central city				-0.4369***				-0.3516***
Central city to secondary centers				0.9270***				1.2231***
Central city to centers' neighboring areas				0.8500**				1.2885***
Central city to peripheral areas				1.6815***				2.6478***
Secondary centers to central city				0.7728***				0.9895***
Secondary centers to secondary centers				-0.1735***				-0.2473***
Secondary centers to centers' neighboring areas				0.5078***				0.7319***
Secondary centers to peripheral areas				1.3905***				2.2727***
Centers' neighboring areas to central city				1.1528***				1.4578***
Centers' neighboring areas to secondary centers				0.6545***				0.5886***
Centers' neighboring areas to centers' neighboring areas				-0.1788***				-0.2119***
Centers' neighboring areas to peripheral areas				0.6629***				1.2682***
Peripheral areas to central city				2.3438***				3.0296***
Peripheral areas to secondary centers				1.5658***				1.4288***
Peripheral areas to centers' neighboring areas				1.2904***				1.4297***
Intercept	-0.0021	0.1081	0.0671	-0.3154***	-0.1768***	-0.1269*	-0.0975	-0.1617***
Random part								
Variance at level 1 (individuals)	0.8350***	0.8337***	0.7735***	0.4385***	0.8574***	0.8567***	0.6895***	0.3729***
Variance at level 2 (municipalities)	0.1338***	0.1668***	0.1066***	0.1681***	0.1013***	0.1042***	0.0857***	0.1680***
Number of observations	4,345	4,345	4,345	4,345	5,384	5,384	5,384	5,384
Conditional intraclass correlation (IC)	0.1381	0.1667	0.1211	0.2770	0.1056	0.1085	0.1106	0.3106
L (β) model	-5867.48	-5875.27	-5694.02	-4515.99	-7314.61	-7313.69	-6730.36	-5149.08
Model improvement χ^2	151.81***	136.22***	498.71***	2854.78***	260.15***	261.99***	1428.66***	4591.20***
Degrees of freedom	28	23	27	36	28	23	27	36
Deviance (misfit of the model)	11734.96	11750.54	11388.05	9031.98	14629.23	14627.38	13460.72	10298.17
Pseudo R^2 (Snijders and Bosker, 2012)	0.0971	0.0675	0.1797	0.4347	0.1078	0.1058	0.2786	0.4966
Pseudo R^2 level 1 (Raudenbush and Bryk, 2002)	0.0236	0.0251	0.0955	0.2907	0.0369	0.0378	0.2255	0.5811
Pseudo R^2 level 2 (Raudenbush and Bryk, 2002)	0.3857	0.2342	0.5104	0.2284	0.4502	0.4343	0.5347	0.0881

APPENDIX 8.1 Multilevel regression models of trip distance: estimation results for work- and non-work-related travel

*Only statistically significant variables are reported. ***, **, * variables significant at 99 percent ($p<0.01$), 95 percent ($p<0.05$) and 90 percent ($p<0.1$).*
a. Coefficients shown here are for the standardized solution. The unstandardized coefficients solution is available on request.
*Note(s): the intercept-only model for work and non-work travel has a statistically significant (β_0) intercept (0.2785*** and 0.2585***), a significant variance at level 1 (0.8552*** and 0.8903***) and at level 2 (0.2178*** and 0.1842***) and a unconditional intraclass correlation of 0.2030 and 0.1714, respectively.*

RANDOM INTERCEPT MODELS DETERMINANTS OF TRIP TIME	WORK-RELATED TRAVEL				NON-WORK-RELATED TRAVEL			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 1	MODEL 2	MODEL 3	MODEL 4
	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]
Fixed part								
Level 1 Individual-specific characteristics								
Gender (reference = male)	-0.1762***	-0.1741***	-0.1741***	-0.0549***	-0.0407	-0.0403	-0.0215	-0.0148
Age cohorts								
36-45 years (reference)								
16-25 years	-0.1225***	-0.1177**	-0.0944**	-0.0163	0.2536***	0.2546***	0.2177***	0.0664**
26-35 years	-0.0533	-0.0481	-0.0302	-0.0085	0.0281	0.0284	0.0452	0.0101
46-55 years	-0.0985**	-0.0969**	-0.0845**	-0.0164	-0.0082	-0.0072	-0.0099	-0.0181
56-65 years	-0.0381	-0.0317	-0.0220	0.0437	0.0302	0.0310	0.0377	0.0064
65+ years	-0.0750	-0.0797	-0.1613	-0.0609	-0.0276	-0.0261	-0.0050	0.0139
Household attributes								
nº of household members	0.0388**	0.0376**	0.0396**	0.0040	0.0543***	0.0544***	0.0424***	0.0019
nº of children (4- years)	0.0252*	0.0239*	0.0204	0.0013	-0.0563***	-0.0563***	-0.0429***	-0.0213***
nº of teenagers (4-16 years)	-0.0213	-0.0184	-0.0184	0.0021	-0.0392**	-0.0386**	-0.0178	0.0060
Professional status								
Unemployed (reference)								
Business owner	-0.1688**	-0.1710**	-0.1407**	-0.0363	0.0436	0.0439	-0.0183	0.0216
Corporate member	0.0828	0.0812	0.1228	0.1616	-0.2912	-0.2941	-0.3200	-0.1028
Family business	-0.2051	-0.1972	-0.1231	0.0277	0.1368	0.1403	0.2617	0.2929**
Full-time worker	-0.0313	-0.0329	-0.0054	0.0563	0.0770	0.0763	0.0716*	0.0923***
Part-time worker	-0.0451	-0.0460	0.0109	0.0630	0.0608	0.0595	-0.0082	0.0908*
Others	-0.0283	-0.0327	-0.0468	0.0440	0.0853	0.0906	0.0643	0.0573
Educational level								
Low (reference)								
Medium	0.1419***	0.1408***	0.1222***	0.0441**	0.2187***	0.2174***	0.1280***	0.0390**
High	0.2391***	0.2385***	0.2031***	0.0735***	0.3073***	0.3053***	0.1641***	0.0125
Driver's license (reference = no license)	0.0147	0.0163	0.0012	0.0214	0.0661*	0.0650*	0.0354	0.0275
Car ownership (reference = no car)	0.0913**	0.0927**	0.1273***	0.0347	0.0743*	0.0777*	0.1203***	0.0367*
Motorcycle license (reference = no license)	-0.0004	-0.0037	-0.0157	0.0138	0.0697	0.0676	0.0631*	0.0182
Motorcycle ownership (reference = no motorcycle)	-0.0500	-0.0492	-0.0530	0.0017	-0.0964	-0.0941	-0.0776	-0.0356
Level 2 Built environment attributes								
Employment density	-0.0170				-0.0263			
Land-use mix	-0.0892***				-0.0402			
Job-housing ratio	-0.0690***				-0.0153			
Distance to the nearest public-transit station	0.0584*				0.0133			
Δ Distance to the nearest highway entrance/exit (infrastructure improvements 1991-2001)	0.0992***				-0.0354			
Presence of urban amenities	-0.2318***				-0.2314***			
Distance to the coast	-0.0473				0.0278			

APPENDIX 8.2 Multilevel regression models of trip time: estimation results for work- and non-work-related travel

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RANDOM INTERCEPT MODELS DETERMINANTS OF TRIP TIME	WORK-RELATED TRAVEL				NON-WORK-RELATED TRAVEL			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 1	MODEL 2	MDOEL 3	MODEL 4
	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]
Level 2 Polycentricity: proximity to centers								
Distance to Barcelona (central city)		0.0602				0.0557**		
Distance to the nearest secondary center (inverse)		-0.0898***				-0.0655***		
Level 2 Polycentricity: size of centers								
Origin: peripheral areas (reference)								
Origin: central city (Barcelona)			-1.2374***				-1.9906***	
Origin: secondary centers			-0.7206***				-1.0203***	
Origin: centers' neighboring areas			-0.3984***				-0.5095***	
Destination: peripheral areas (reference)								
Destination: central city (Barcelona)			0.8110***				1.7255***	
Destination: secondary centers			0.7460***				0.9811***	
Destination: centers' neighboring areas			0.4068***				0.5329***	
Level 2 Polycentricity: aggregate size of centers through their integration								
Peripheral areas to peripheral areas (reference)								
Central city to central city				-0.5544***				-0.3788***
Central city to secondary centers				1.3690***				1.8997***
Central city to centers' neighboring areas				1.3148***				1.7030***
Central city to peripheral areas				1.7057***				2.4530***
Secondary centers to central city				1.1790***				1.6384***
Secondary centers to secondary centers				-0.2218***				-0.2423***
Secondary centers to centers' neighboring areas				0.8243***				1.2585***
Secondary centers to peripheral areas				1.4350***				2.2840***
Centers' neighboring areas to central city				1.3566***				1.8477***
Centers' neighboring areas to secondary centers				0.9376***				1.1981***
Centers' neighboring areas to centers' neighboring areas				-0.2038***				-0.2268***
Centers' neighboring areas to peripheral areas				0.8095***				1.3743***
Peripheral areas to central city				2.0462***				2.6318***
Peripheral areas to secondary centers				1.4778***				1.6699***
Peripheral areas to centers' neighboring areas				1.2854***				1.5329***
Intercept	0.0170	0.2109***	0.2040	-0.3483***	-0.1550***	-0.0053	-0.1910***	-0.2219***
Random part								
Variance at level 1 (individuals)	0.8043***	0.8036***	0.7604***	0.3085***	0.8347***	0.8342***	0.6627***	0.2476***
Variance at level 2 (municipalities)	0.0976***	0.1487***	0.0790***	0.1262***	0.0773***	0.0896***	0.0308***	0.0976***
Number of observations	4,345	4,345	4,345	4,345	5,384	5,384	5,384	5,384
Conditional intraclass correlation (IC)	0.1082	0.1561	0.0941	0.2904	0.0847	0.0970	0.0444	0.2827
L (β) model	-5773.30	-5791.49	-5644.57	-3755.98	-7231.30	-7236.18	-6583.87	-4037.57
Model improvement χ^2	170.61***	134.24***	428.06***	4205.24***	298.11***	288.35***	1592.98***	6685.58***
Degrees of freedom	28	23	27	36	28	23	27	36
Deviance (misfit of the model)	11546.60	11582.98	11289.15	7511.97	14462.61	14472.37	13167.74	8075.15
Pseudo R^2 (Snijders and Bosker, 2012)	0.0950	0.0445	0.1578	0.5638	0.0736	0.0616	0.2955	0.6494
Pseudo R^2 level 1 (Raudenbush and Bryk, 2002)	0.0271	0.0280	0.0790	0.6269	0.0496	0.0502	0.2454	0.7181
Pseudo R^2 level 2 (Raudenbush and Bryk, 2002)	0.4253	0.1249	0.5351	0.2570	0.2724	0.1560	0.7099	0.0814

APPENDIX 8.2 Multilevel regression models of trip time: estimation results for work- and non-work-related travel

*Only statistically significant variables are reported. ***, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1).*
a. Coefficients shown here are for the standardized solution. The unstandardized coefficients solution is available on request.
*Note(s): the intercept-only model for work and non-work travel has a statistically significant (β_0) intercept (0.2333*** and 0.2131***), a significant variance at level 1 (0.8268*** and 0.8783***) and at level 2 (0.1699*** and 0.1062***) and an unconditional intraclass correlation of 0.1705 and 0.1079, respectively.*

RANDOM INTERCEPT MODELS DETERMINANTS OF CO_2 EMISSIONS PER CAPITA	WORK-RELATED TRAVEL				NON-WORK-RELATED TRAVEL			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 1	MODEL 2	MODEL 3	MODEL 4
	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]
Fixed part								
Level 1 Individual-specific characteristics								
Gender (reference = male)	-0.1504***	-0.1501***	-0.1453***	-0.0611**	-0.0429	-0.0418	-0.0314	-0.0274
Age cohorts								
36-45 years (reference)								
16-25 years	-0.1092**	-0.1096**	-0.0810*	-0.0258	0.2274***	0.2284***	0.1986***	0.1122**
26-35 years	-0.0323	-0.0299	-0.0071	0.0059	0.1183**	0.1173**	0.1287**	0.0989**
46-55 years	-0.0670	-0.0688	-0.0517	0.0003	0.0114	0.0131	0.0066	0.0022
56-65 years	-0.0320	-0.0323	-0.0132	0.0324	0.0688	0.0711	0.0716	0.0491
65+ years	-0.0117	-0.0210	-0.0929	-0.0381	0.0503	0.0517	0.0623	0.0660
Household attributes								
nº of household members	0.0079	0.0078	0.0092	-0.0150	0.0365**	0.0362**	0.0257*	0.0026
nº of children (4- years)	0.0275*	0.0262*	0.0229*	0.0139	-0.0563***	-0.0564***	-0.0475***	-0.0335***
nº of teenagers (4-16 years)	0.0006	0.0015	0.0031	0.0181	-0.0219	-0.0210	-0.0075	0.0073
Professional status								
Unemployed (reference)								
Business owner	-0.0913	-0.0994	-0.0615	0.0037	0.1082	0.1064	0.0768	0.0975
Corporate member	0.2387	0.2230	0.2940*	0.3271**	-0.6131	-0.6094	-0.5955	-0.4119
Family business	-0.1061	-0.1026	-0.0231	0.1203	0.2501	0.2497	0.3176	0.3394
Full-time worker	-0.0089	-0.0104	0.0181	0.0594	0.0475	0.0462	0.0388	0.0479
Part-time worker	-0.0242	-0.0264	0.0346	0.0573	-0.0495	-0.0513	-0.0932	-0.0190
Others	0.0400	0.0379	0.0305	0.0912	-0.2072	-0.2014	-0.2001	-0.1651
Educational level								
Low (reference)								
Medium	0.1004***	0.0974***	0.0800**	0.0287	0.1864***	0.1861***	0.1277***	0.0760**
High	0.1863***	0.1848***	0.1469***	0.0618*	0.1836***	0.1838***	0.0889*	0.0080
Driver's license (reference = no license)	0.0789*	0.0787*	0.0661	0.0822**	0.0749**	0.0755**	0.0515	0.0461
Car ownership (reference = no car)	0.2860***	0.2855***	0.3234***	0.2557***	0.3098***	0.3101***	0.3363***	0.2877***
Motorcycle license (reference = no license)	0.0430	0.0405	0.0281	0.0502	0.1105**	0.1107**	0.1113***	0.0707*
Motorcycle ownership (reference = no motorcycle)	-0.0783	-0.0803	-0.0801	-0.0421	-0.1553**	-0.1537**	-0.1436**	-0.1200**
Level 2 Built environment attributes								
Employment density	-0.0540				-0.0863**			
Land-use mix	-0.0950***				0.0094			
Job-housing ratio	-0.0340				0.0449			
Distance to the nearest public-transit station	0.0951***				0.0775**			
Δ Distance to the nearest highway entrance/exit (infrastructure improvements 1991-2001)	0.0506*				-0.0983***			
Presence of urban amenities	-0.1530**				-0.1075*			
Distance to the coast	-0.0172				0.0224			

APPENDIX 8.3 Multilevel regression models of CO_2 emissions per capita: estimation results for work- and non-work-related travel

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RANDOM INTERCEPT MODELS DETERMINANTS OF CO_2 EMISSIONS PER CAPITA	WORK-RELATED TRAVEL				NON-WORK-RELATED TRAVEL			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 1	MODEL 2	MODEL 3	MODEL 4
	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]	COEF.(STD.)[A]
Level 2 Polycentricity: proximity to centers								
Distance to Barcelona (central city)		0.1530***				0.1413***		
Distance to the nearest secondary center (inverse)		-0.1072**				-0.1009**		
Level 2 Polycentricity: size of centers								
Origin: peripheral areas (reference)								
Origin: central city (Barcelona)			-1.2662***				-1.5705***	
Origin: secondary centers			-0.9351***				-1.1059***	
Origin: centers' neighboring areas			-0.6382***				-0.6890***	
Destination: peripheral areas (reference)								
Destination: central city (Barcelona)			0.8612***				1.2754***	
Destination: secondary centers			0.7514***				0.9058***	
Destination: centers' neighboring areas			0.5010***				0.6055***	
Level 2 Polycentricity: aggregate size of centers through their integration								
Peripheral areas to peripheral areas (reference)								
Central city to central city				-0.3590***				-0.2799***
Central city to secondary centers				0.4684***				0.7796*
Central city to centers' neighboring areas				0.5886***				0.5807***
Central city to peripheral areas				1.2908***				2.1333***
Secondary centers to central city				0.4761***				0.4998***
Secondary centers to secondary centers				-0.1853***				-0.1949***
Secondary centers to centers' neighboring areas				0.4294***				0.4724***
Secondary centers to peripheral areas				1.2417***				1.2909***
Centers' neighboring areas to central city				0.8516***				0.9732***
Centers' neighboring areas to secondary centers				0.5720***				0.5469***
Centers' neighboring areas to centers' neighboring areas				-0.1482**				-0.1234*
Centers' neighboring areas to peripheral areas				0.4775***				0.9443***
Peripheral areas to central city				2.0366***				2.1187***
Peripheral areas to secondary centers				1.4739***				1.3591***
Peripheral areas to centers' neighboring areas				1.1751***				1.2005***
Intercept	-0.1773	-0.0777	-0.0742	-0.4197***	-0.2312*	-0.1737**	-0.1249*	-0.2093***
Random part								
Variance at level 1 (individuals)	0.7998***	0.7981***	0.7506***	0.5367***	0.8405***	0.8402***	0.7543***	0.6018***
Variance at level 2 (municipalities)	0.1358***	0.1883***	0.1252***	0.1683***	0.1493***	0.1672***	0.1589***	0.2132***
Number of observations	4,345	4,345	4,345	4,345	5,384	5,384	5,384	5,384
Conditional intraclass correlation (IC)	0.1452	0.1909	0.14302	0.2388	0.1508	0.1659	0.1740	0.2615
L (β) model	-5776.80	-5789.28	-5637.97	-4943.17	-7281.46	-7286.57	-6999.18	-6421.82
Model improvement χ^2	315.33***	290.37***	592.97***	1982.58***	376.47***	366.25***	941.04***	2095.75***
Degrees of freedom	28	23	27	36	28	23	27	36
Deviance (misfit of the model)	11553.60	11578.55	11275.95	9886.34	14562.93	14573.14	13998.36	12843.65
Pseudo R^2 (Snijders and Bosker, 2012)	0.1625	0.1171	0.2161	0.3689	0.1305	0.1151	0.1979	0.2841
Pseudo R^2 level 1 (Raudenbush and Bryk, 2002)	0.0553	0.0572	0.1134	0.3660	0.0591	0.0594	0.1556	0.1304
Pseudo R^2 level 2 (Raudenbush and Bryk, 2002)	0.4987	0.3057	0.5379	0.3789	0.3908	0.3180	0.3518	0.3263

APPENDIX 8.3 Multilevel regression models of CO_2 emissions per capita: estimation results for work- and non-work-related travel

*Only statistically significant variables are reported. ***, **, * variables significant at 99 percent (p<0.01), 95 percent (p<0.05) and 90 percent (p<0.1).*
a. Coefficients shown here are for the standardized solution. The unstandardized coefficients solution is available on request.
*Note(s): the intercept-only model for work and non-work travel has a statistically significant (β_0) intercept (0.3201*** and 0.2582***), a significant variance at level 1 (0.8466*** and 0.8933***) and at level 2 (0.2711*** and 0.2451***) and an unconditional intraclass correlation of 0.2425 and 0.2153, respectively.*

Curriculum vitae

Jaume was born on 11 July 1986 in Barcelona, Catalonia. In September 2004, he began studying Architecture at Universitat Politècnica de Catalunya (UPC), where he specialized in urbanism and earned his 6-year Bachelor of Architecture (with honors) in May 2010.

Trained both in architecture and urbanism, Jaume acquired skills to address design issues on both small (building and urban) and large (territorial) scales. His interest in gaining additional knowledge based on empirical evidence to constructively criticize the then-current methodological approaches in the field of urbanism/spatial planning prompted him to begin studying for an M.Sc. in Urban Management and Valuation at Universitat Politècnica de Catalunya in September 2009 while he continued to pursue his Bachelor of Architecture.

In November 2010, Jaume was awarded the highly competitive FPI-UPC grant by Universitat Politècnica de Catalunya to conduct further doctoral studies; in addition, he obtained his M.Sc. in Urban Management and Valuation (with honors) in January 2011. Since January 2011, he has conducted doctoral research at Universitat Politècnica de Catalunya and Delft University of Technology.

During Jaume's Ph.D. studies, he has developed a strong multidisciplinary profile, combining insights from spatial planning, urban and regional economics, economic geography, and transport geography, and he has shown a passionate devotion to econometrics, which is primarily demonstrated through the papers that he has presented at several international conferences focused on a variety of disciplines—e.g., urban and regional economics at ERSA and NARSC conferences, geography at the AAG Annual Meeting and both urban and regional studies at the RSA conference.

In December 2015, Jaume completed his Ph.D. thesis in the OTB Department–Research for the Built Environment, which is part of the Faculty of Architecture and the Built Environment, Delft University of Technology. That thesis resulted in this book.

Despite strong efforts made by scholars to study the polycentric spatial organization of agglomeration in metropolitan areas, there is still no consensus about the conceptualization (i.e., identification and measurement) of polycentricity and its economic, social, and environmental (dis)advantages. Additionally, little is known in the policy realm about how polycentric development can be conceptualized in spatial plans and how the assumed benefits of polycentricity can be realized in planning practice. This is despite the fact that more than 75 percent of recent spatial plans developed for large metropolitan areas in OECD countries consider polycentric development to be the best strategy for managing urban development. It is therefore crucial to gain more insights into the multiple and reciprocal relationships among the polycentric spatial structure of metropolitan areas; their economic, social, and environmental performance; and how these metropolitan areas are planned through the elaboration of spatial plans. A deep understanding of these relationships will help to successfully address impending economic, social, and environmental challenges for people who currently live in metropolitan areas—this includes approximately 50 percent of the world's population, considering only the non-metropolitan and metropolitan populations of OECD countries in 2014.

This issue of A+BE provides valuable insights by conducting research that links knowledge of polycentric constellations and their economic, social, and environmental effects to planning practice and policy in metropolitan areas. Specifically, this book develops policy/discourse analysis to examine how the makers of spatial plans have addressed polycentric development over time. Moreover, this book contributes to the literature by proposing conceptual and empirical frameworks for identifying/measuring polycentricity on the intra-metropolitan scale and for broader testing of the effects of polycentricity on metropolitan performance. Evidence-informed guidelines for spatial development strategies are then provided. These guidelines are built upon the empirical substantiation that centers of a polycentric metropolitan structure are able to foster better performance of a metropolitan area when they are more spatially integrated, bigger, and more proximate to their smaller neighboring cities.

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