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Summary

This thesis identified the effects of agglomeration economies and the degree of polycentricity on Mexican urban regions' labour productivity for the whole economy and the two most significant sectors: manufacturing and services. To achieve this, two statistical techniques were used based on cross-sectional data: OLS and TSLS, which allows for eliminating the endogeneity relationship between productivity and size and spatial structure. The results obtained are summarised into five main findings:

- Finding 1. Positive and significant effects of agglomeration on productivity are mainly observed in the service sector but not in manufacturing. These effects surpass 21% in all the specifications, which notably exceeds the results observed in other studies in the region.
- Finding 2. The degree of polycentricity has a negative effect on productivity when analysing results by sector, not in the aggregate. A more evenly distributed urban population across cities affect manufacturing (only under OLS specifications) and service productivity.
- Finding 3. In the service sector, the effect of polycentricity increases when the size of urban regions grows. For the manufacturing sector, mixed results are observed. This positive association indicates that by keeping the degree of polycentricity constant, cities with more inhabitants will reach higher levels of labour productivity.
- Finding 4. In Mexico, there are no significant and stable differences in the aggregate labour productivity of the different macro-regions. The differences found depend highly on the specifications used and the sector analysed. In the OLS models for the service sector, it is possible to identify higher productivity levels in the Centre-west to and North macro-regions.
- Finding 5. The effect of agglomeration and the degree of polycentricity vary significantly between the manufacturing and service sectors, where the greatest effects of size and urban structure are reflected.

This work contributes to close the gaps in the evidence available on agglomeration economics and spatial structure on economic performance in the global south, particularly in Latin America. The empirical results could serve to feed national policies with an explicit spatial focus that seeks to improve the productivity of urban regions by reducing territorial inequalities that prevail in Mexico. Achieving a more balanced and convergent development path requires awareness of the importance of place-based policies in a context of economic globalisation and consolidation of trade liberalisation with North America. More in-depth empirical research is required to refine the findings based on more disaggregated territorial data, new information generation techniques, and longitudinal econometric methods.

Keywords

Agglomeration economics, urban spatial structure, polycentricity, labour productivity.

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Foreword

Cities are dense concentrations of people and economic activities in which external benefits are produced for individuals and companies because they are located in the same urban space. These agglomeration benefits or economies impact different socioeconomic dimensions, including productivity. When cities double their population size, increases in productivity between 3% and 8% are observed, and up to 16% in Latin American countries. However, these benefits have a limit.

When cities reach certain size thresholds, agglomeration costs exceed their benefits, motivating people and economic activities to relocate to other urban areas. In this way, increasingly polycentric urban patterns are generated in which different urban centres interact, impacting their economic performance. Demographic size and degree of polycentricity are two dimensions that impact urban productivity.

This thesis identified the effects of agglomeration economies and the degree of polycentricity on the labour productivity performance of Mexican urban regions using cross-sectional data from 2020 and OLS and TSLS econometric techniques. The results indicate that the size and spatial structure impact, mainly, the labour productivity of the service sector but not that of the manufacturing sector.

Table of Contents

List of Figures

List of Tables

Abbreviations

CONAPO	National Population Council
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
IHS	Institute for Housing and Urban Development Studies
INEGI	National Institute of Statistics and Geography
IV	Instrumental variables
NAFTA	North American Free Trade Agreement
OLS	Ordinary least squares
PUR	Polycentric urban regions
SCIAN	North American Industrial Classification System
SEDATU	Ministry of Agrarian, Territorial and Urban Development
SEGOB	Ministry for Internal Affairs
TSLS	Two-stage least squares
UNS	Urban National System
USMCA	Free trade agreement between Mexico, the United States and Canada
VIF	Variance Inflation Factor

1. Introduction

1.1.City as density and form

From an urban economics perspective, cities are dense agglomerations of people and economic activities that produce unique socio-spatial dynamics that distinguish them from the non-urban (Scott & Storper, 2015). One of these dynamics is called agglomeration economies, a set of external benefits for individuals and companies for being located in the same urban space (Ellison et al., 2010; Glaeser, 2010; Parr, 2004).

The literature on the economic effects generated by spatial agglomeration is more than extensive on the benefits of the size and density of cities on different socioeconomic dimensions, including productivity (Ahlfeldt & Pietrostefani, 2019). However, the same literature points out that when the city reaches a certain population level, these benefits tend to decrease while the costs associated with agglomeration grow (Richardson, 1995; Wheeler, 2003). This fundamental trade-off between economies and diseconomies of agglomeration explains why cities do not increase infinitely (Fujita & Thisse, 2004).

When diseconomies appear and overcome the urban benefits, some economic activities tend to relocate to other cities in the urban system of a country or region as a strategy to reduce external agglomeration costs (Fujita & Ogawa, 1982). This process of relocation of productive activities is accompanied by a strong process of demographic grouping (Duranton & Puga, 2020), contributing to modifying the spatial structure of regional urban systems from a relatively monocentric profile to a more polycentric one. In addition to size, monocentricity-polycentricity pattern, the degree to which employment or urban population are concentrated in one or more cities of a metropolitan area (Meijers & Burger, 2010), appears as a second dimension of analysis that can impact the economic performance of cities.

1.1.1. Problem statement and relevance of the topic

In urban economics, there is a particular interest in studying the effects of agglomeration on urban economic performance, specifically through productivity, a canonical measure to estimate agglomeration economies (Grover et al., 2022). Comprehensive and well-documented empirical evidence in this regard shows that size matter: when urban areas reach twice its size, productivity reaches gains between 3% and 8% (Melo et al., 2009; Rosenthal & Strange, 2004), although in Latin American countries these gains can reach levels from 6% to 16% - increases that more than even triple and quadruple estimations for developed nations (Grover, Lall, & Timmis, 2021).

Currently, the theoretical research indicates that the agglomeration economies are progressively correlated with more polycentric regional urban structures, besides monocentric ones (Meijers, 2013), as a consequence of the accelerated process of global urbanization and its effects on the spatial structure of cities (Scott & Storper, 2015). In this regard, an increasing amount of literature on the effect of spatial configuration on productivity is available. The empirical research takes into consideration the monocentric-polycentric dimension to measure the distribution of population and employment in urban space and, based on that, isolated its effects on productivity. Examples of this approach have been developed primarily in Europe and countries like the United States and China. However, the evidence is much less for other countries in the global south, particularly in regions such as Latin America.

The empirical evidence on the results polycentricity on economic performance is not conclusive. Some results show that networks of proximate cities can reduce the adverse effects of agglomeration (Johansson & Quigley, 2004) but without being a substitute for the economic externalities of urbanization observed in larger cities (Meijers & Burger, 2010). Even, there are other studies that find that polycentricity per se can harm productivity, while in interaction with size a negative effect may be found (Ouwehand et al., 2022). The latter suggests that polycentricity only works when urban cores in regions are equally (small) in size.

In the case of Mexico, the slight research available also shows inconclusive results on the effect of agglomeration and regional urban structure on productivity. Quintero and Roberts (2018) found a negligible positive association between density and productivity, while Monkkonen et al. (2020), as well as Montejano et al. (2020), found a negative effect of the density and fragmentation of the urban footprint on labour productivity in the manufacturing sector. This context makes it particularly interesting to generate more evidence of the effect of agglomeration and regional urban structure on the economic performance of Mexico. In the last four decades, this country has experienced important processes of population and productive activities relocation from the highly populated central region around Mexico City to north-central and northern states, entities well-connected with transport infrastructure and geographically closest to the border with the United States. This process has had significant implications for the Mexican regional urban system regarding polycentricity (Garza & Schteingart, 2010; Sobrino, 2002).

1.1.2. Research objectives and questions

1.1.2.1. Objectives

Based on the above, the main objective of this thesis is to identify the agglomeration and polycentric-monocentric spatial structure effects on the economic performance of Mexican urban regions proxied by labour productivity.

At the same time, the secondary objectives are:

- Determine whether the current multicentric spatial organization of the Mexican urban system generates benefits for spatially close urban regions due to sharing economies of agglomeration.
- Identify if the agglomeration effects of the spatial structure of urban regions observe macro regional and sectoral differences between manufacturing and service sectors or if they are constant at the national level and regardless of the productive sector analysed.
- Contribute to closing gaps in the availability of evidence of the effect of regional urban structure on economic performance in Latin American countries like Mexico that, in recent decades, have moved from a highly centralised urban system to an increasingly polycentric one.

1.1.2.2. Research question

To the stated objectives, the main research question of this thesis is the following:

- What is the agglomeration effect of the polycentric-monocentric spatial structure of Mexican urban regions on economic performance, measured by labour productivity?

At the same time, three sub-questions are proposed to answer the general research question:

1. In Mexico, is there a positive relationship between the agglomeration economies generated by the size of the urban regional population and labour productivity?

2. Is the effect of the polycentric regional urban structure independent of the size of the urban regions, or does it increase/decrease when the urban region size grows (interaction effect)?
3. Does the effect of the regional urban structure on economic performance present significant differences between the country's main macro regions? That is, are there differences in productivity attributable to macro regional effects?
4. Is the effect of the spatial structure of Mexican urban regions significantly different for large sectors of economic activity, particularly for manufacturing and services sectors?

1.2.Thesis general structure

This thesis is integrated into five chapters, following the introduction as chapter one. In the second part, a conceptual overview of economies and diseconomies of agglomerations, as well as the effects of urban structure on the economic performance of cities, is presented with some of the extensive empirical evidence in this field. The third chapter describes the operationalisation of the main concepts of agglomerations and regional urban structure, as well as the data sources and variables used. In chapter four, the different econometric model specifications based on previous relevant literature and the main results obtained are presented. The last section corresponds to conclusions and final remarks for future research, as well as their relevance in the case of Mexico.

2. Literature review and research hypothesis

2.1. Agglomeration economies

The cities of the world occupy around 0.5% of the total terrestrial surface (Angel et al., 2011; Dijkstra et al., 2021), but they concentrate 58% of the population and generate close to 80% of the Gross Domestic Product (GDP) of the planet (UN-Habitat, 2022). From an economic point of view, the dense agglomerations of people and economic activities in cities cannot be entirely explained by differences in the physical geography attributes, the distribution of natural resources, nor by the mere reduction in transportation costs that the proximity among people and economic activities implies (Ellison & Glaeser, 1999; Fujita & Thisse, 1996; Henderson et al., 2017; Ottaviano & Thisse, 2003).

Complementary explanations acknowledge the existence of some source of increasing returns to scale generated in cities benefiting those placed there by improving their wages, productivity or economic performance. These returns, called agglomeration economies, are related to the characteristics of the space beyond the heterogeneity of the underlying land (Ellison et al., 2010; Glaeser, 2010; Puga, 2010) and are entirely external to the firms and persons located in the space (Parr, 2002). These economies develop a cumulative process that encourages the gradual concentration of economic activities, accompanied by a strong demographic grouping process that accentuates the differences throughout the space (Duranton & Puga, 2020).

There is extensive and well-documented literature that shows the agglomeration benefits on economic growth, productivity, and wages, but also on other socioeconomic dimensions that range from the higher propensity to innovate to the reduction of polluting emissions per capita going through the improvement in accessibility to amenities and energy efficiency (Ahlfeldt & Pietrostefani, 2019; Bettencourt et al., 2007; Glaeser et al., 2001; Glaeser, 2012).

However, when the size and population density of cities reach certain thresholds, agglomeration benefits are marginally reduced, while the associated costs, pecuniary (e.g., land and housing prices) and non-pecuniary (e.g., crime, traffic congestion, or pollution), increases (Frick & Rodríguez-Pose, 2018; Richardson, 1995; Wheeler, 2003). These costs, called agglomeration diseconomies, are in tension with the benefits of size and density. This fundamental trade-off explains not only why cities do not increase to infinity (Fujita & Thisse, 2004), but also how fast the speed of its growth is and, above all, the changes in its spatial structure over time (Richardson, 1995).

Beyond analysing the question of defining the optimal size of cities in which the economies and diseconomies of agglomeration are balanced (Batty, 2008), research in the field of urban economics has concentrated on explaining the effect of the agglomeration on economic performance, particularly from observing the increase in productivity. This emphasis is partly a consequence of the intertwined relationship between urban agglomeration and regional economic growth theories (McCann & van Oort, 2009; van Oort, 2002). Since agglomeration economies, by definition, result in productivity gains, it is natural to use this indicator as evidence of the existence and magnitude of these external benefits (Meijers, 2013).

2.1.1. Effect of size and density on productivity

In urban economics, three primary sources of agglomeration economies that imply an increase in urban productivity are recognized: sharing, matching, and learning. The first refers to the characteristic of indivisibility of certain goods, services, infrastructures, and amenities in cities as a consequence of the high fixed costs for their production; this dimension may also include gains produced by sharing common suppliers of diverse inputs by the possibility of obtaining benefits derived from specialization and by reducing risks. The second one, matching, concerns to the advantages brought by employers and job seekers, buyers and sellers, and even business partners regarding the increased probability of making a match that meets their needs and the expected quality of each match when the size of the markets increases. Finally, the learning process refers to the mechanisms of generation, dissemination and accumulation of knowledge created in cities due to the development and widespread adoption of new technologies, practices, and processes (Duranton & Puga, 2004; Puga, 2010)

Going from the theoretical definition of these three sources of agglomeration to their empirical estimation is not a simple task because their effects on productivity are amalgamated (Puga, 2010); however, it is possible to estimate the aggregate effects of density by calculating the agglomeration size elasticity, that is, the percentage change in productivity (e.g. total factor productivity, labour productivity, etc.) generated by the percentage change in the size of the cities (Grover et al., 2022).

There is a vast field of work on estimating these elasticities, from the pioneering work of Sveikauskas (1975) on labour productivity. The main research includes studies developed for Europe (Artis et al., 2011; Ciccone, 2002; Stehrer & Foster-McGregor, 2008) and for specific countries from the global north, as well as for China:

- United States (Abel et al., 2012; Ciccone & Hall, 1993; Meijers & Burger, 2010; Rosenthal & Strange, 2004; Wheeler, 2001).
- Canada (Baldwin et al., 2007).
- France (Combes et al., 2008; Combes et al., 2012).
- Germany (Ahlfeldt et al., 2015).
- Italy (Cingano & Schivardi, 2003).
- Spain (Paluzie et al., 2008).
- The Netherlands (Broersma & Oosterhaven, 2009; Gorter & Kok, 2009; Ouwehand et al., 2022).
- United Kingdom (Graham et al., 2010; Graham & Kim, 2008).
- Japan (Davis & Weinstein, 2001; Nakamura, 1985).
- South Korea (Azari et al., 2016; Lee, Y. & Zang, 1998).
- China (Au & Henderson, 2006; Fan, 2007; Ke, 2010; Li, C. & Gibson, 2014).

These types of studies are less frequent in the countries of the global south. Some examples are the cases of India (Lall et al., 2004), Vietnam (Bac, 2023) and Indonesia (Wibowo & Kudo, 2019). In Latin America, there are examples in Brazil (Barufi et al., 2016; Henderson, 1986), Colombia (Duranton, 2016) and Chile (Saito & Gopinath, 2009). At the regional level, Quintero & Roberts (2018) show the productivity premiums generated by agglomeration economies in 16 countries, including Mexico, where the effect is negligible (0.3%).

For the Mexican case, Montejano et al. (2020) and Monkkonen et al. (2020) find a negative effect of urban density and urban footprint fragmentation on manufacturing sector labour productivity. Although the agglomeration effect is contrary to what was expected, the authors argue that this may be a consequence of the accelerated process of urban expansion in Mexican cities driven by the construction of hundreds of thousands of housings and the placement of manufacturing industries on the outskirts of the main metropolis, reflecting a process of decentralization abroad of the central urban areas. In this way, the manufacturing sector could achieve a higher degree of productivity in a polycentric and, at the same time, concentrated-dispersed pattern. However, more evidence is needed to identify the effect of agglomeration and regional urban structure on Mexican urban areas' productivity.

Beyond a few exceptions, the empirical evidence shows a consensual agreement on the positive effect of agglomeration on productivity. However, Melo, Graham, & Noland (2009) emphasise that agglomeration size elasticities are highly contextual and depend on country-specific effects, the type of industry analysed, and the choice of model used, so there is no reason to expect similar magnitudes between sectors, cities or countries.

In some countries like the United States, increases in productivity can reach up to 10% (Meijers & Burger, 2010), although the average typically ranges from 3% to 8% (Abel et al., 2012; Ciccone & Hall, 1993; Rosenthal & Strange, 2004), while in Europe agglomeration elasticities range from 4.5% to 6%, on average (Artis et al., 2011; Ciccone, 2002). In a meta-analysis of the productive advantages of cities in 54 countries, Donovan, de Graaff, de Groot, & Koopmans (2022) found that although there are differences in productivity attributable to methodological specifications and individual country effects, it is likely that agglomeration elasticities are in the range of 2.7% to 6.4%. This range coincides with the results of other studies that estimate productivity gains between 4% and 6%, depending on whether labour productivity or total factor productivity is estimated (Ahlfeldt & Pietrostefani, 2019).

The effects of agglomeration on productivity are markedly different in developing or low-income countries. It is estimated that doubling the size of the city is associated with improvements in productivity between 6% and 16% for Latin American nations and up to 19% in China, 12% in India and 17% in African countries. These increases triple and quadruple the effects in developed nations, estimated between 4% and 6% (Grover, Lall, & Timmis, 2021). Similar studies indicate that productivity increases in low-income countries are at least double those observed in high-income counterparts: 4% vs 8% (Ahlfeldt & Pietrostefani, 2019).

Although the empirical evidence is strong on the effect of agglomeration on productivity, this aggregate effect assumes a uniform distribution of the population in space, omitting other dimensions of the urban nature that could affect productivity levels, such as accessibility conditions, land uses or spatial structure (Duque et al., 2022; Lopez & Hynes, 2003; Melo et al., 2017). The current theoretical research suggests that the agglomeration benefits are progressively correlated with more dispersed urban structures (Meijers, 2013). The following two sections present the literature review on how regional urban structure affects productivity.

2.2.Regional urban structure and economic performance

In recent decades, the accelerated process of global urbanization has generated significant changes in the structure of cities (Scott & Storper, 2015), favouring the development of polynuclear urban regions, in which different urban centres or cities closely-located and well-connected interact (Meijers, 2013; van Oort et al., 2010). This means that the agglomeration economies are not restricted to a single urban centre but instead have a metropolitan or regional scope in which several sub-centres share agglomeration advantages (Meijers et al., 2016; Phelps & Ozawa, 2003). This process also reflects the tendency of various economic activities to relocate to other urban areas in a region as a strategy to reduce agglomeration diseconomies (Fujita & Ogawa, 1982; Lee, B. & Gordon, 2007).

2.2.1. Polycentricity and monocentricity

Capturing the effects of the spatial structure of urban regions on productivity is particularly relevant given the emergence of polynuclear cities (Batty, 2001), also called polycentric urban systems (Brezzi & Veneri, 2015) or city networks (Camagni & Salone, 1993) to find out if the agglomeration economies developed in this type of urban regions are similar in magnitude to those generated in a monocentric urban area (Meijers, 2008a; Meijers et al., 2016).

The literature recognizes that there is a process of regionalization of agglomeration economies that allows more or less close cities to work in a network reducing the costs generated by excessive density (Capello & Camagni, 2000; Parr, 2002), an idea based on Alonso's notion (1973) about the possibility that small or medium-sized cities in a metropolitan or megalopolitan urban complex borrow dimensions from one another and, in this way, achieve productivity beyond what is expected for their counterparts of similar size that are isolated to the rest of the cities (Meijers & Burger, 2017).

Studies on the effect of polycentricity on productivity come from two perspectives. On the one hand, a morphological approach based on the distribution or size of specific internal characteristics of the urban area, such as population or employment, and on the other, a functional approach focused on analysing how the relationships between urban centres configure the territory by providing functions that define territorial hierarchies (Brezzi & Veneri, 2015; Burger & Meijers, 2012; Ouwehand et al., 2022). This work opts for the morphological approach of polycentricity since it seeks to be comparable with previous research and because the functional approach would imply the development of a substantially more complex analysis model given the multidirectional nature of the relationships between urban centres (Ouwehand et al., 2022). Additionally, authors such as Burger and Meijers (2012) have shown that most regions tend to be more polycentric morphologically than functionally.

From a morphological perspective, the relationship between polycentricity and productivity has been studied mainly from the effect of the degree of polycentricity-monocentricity of urban regions, that is, the degree to which employment or the urban population are concentrated in a city or, on the contrary, it is divided into different cities of a polynuclear area (Meijers & Burger, 2010). From this approach, polycentricity means not only the existence of different cities in a region, but the balance between their size distribution: in polycentric urban arrangements, there is no clear dominance of one city over the rest in any dimension; that is, there is a lack of an evident hierarchy between the cities.

Examples of this perspective can be found on both regional and national scales. In Europe, the studies by Meijers, Burger and Hoogerbrugge (2016) and Ouwehand, van Oort and Cortinovis (2022) stand out at the regional level, while at the national scale, it is possible to find cases in Italy (Veneri & Burgalassi, 2012), Spain (Tortosa-Ausina et al., 2011), and The Netherlands (Meijers, 2005; Meijers, 2008b).

In other regions of the world, there is evidence for Latin America (Duque et al., 2022) and for countries like South Korea (Kwon & Seo, 2018) and Vietnam (Bac, 2023), as well multiples studies for China (Chen et al., 2021; Derudder & Liu, 2019; Li, W. et al., 2022; Li, Y. & Liu, 2018; Li, Y. & Du, 2022; Wang et al., 2019) and the United States (Fogarty & Garofalo, 1988; Lee, B. & Gordon, 2007; Meijers & Burger, 2010; Meijers, 2013). In addition, Brezzi and Veneri (2015) show the relationship between polycentricity and GDP per capita at the metropolitan, regional and national scale for Organisation for Economic Co-operation and Development countries, finding opposite results depending on the scale.

Despite the diversity of studies on the relationship between the polycentric regional urban structure and productivity, the results are inconclusive: while polycentric urban systems can reduce the magnitude of agglomeration diseconomies because, to some extent, agglomeration positive externalities are shared among cities (Johansson & Quigley, 2004), polynuclear urban areas are not a perfect substitute for the positive externalities observed in larger cities as a consequence of the fact that the effect of polycentricity on productivity decreases when the size of the cities increases (Meijers & Burger, 2010). Other studies find that polycentricity can even harm productivity, although this disappears when the size of urban areas is considered (Ouwehand et al., 2022). In this sense, the effect of polycentricity on productivity interacts with the size of the agglomerations, generating non-constant effects.

These ambivalent findings make it interesting to analyse more specific cases, such as the one proposed in this research for the case of Mexico, a country that, in the last four decades, has experienced important processes of population and productive activities relocation from industrial centres concentrated in a few urban areas (e.g., Mexico City, Guadalajara, and Monterrey), to intermediate ones in the centre and north. This process is partially a consequence of an accelerated commercial opening and economic integration with the North American region, which began in the 1980s with the country's entry into the General Agreement on Tariffs and Trade (GATT) and with the subsequent signing of the North American Free Trade Agreement (NAFTA) in 1994 (Mendoza-Cota & Pérez-Cruz, 2007).

In Mexico, the economic integration with global markets has had significant implications for the urban system regarding the consolidation of an increasingly polycentricity in a greater number of metropolitan areas (Garza & Schteingart, 2010; Sobrino, 2002). Since the beginning of trade liberalisation, the geographic relocation of manufacturing activities, strongly linked to exports, has generated agglomeration patterns in the central-northern regions and on the country's northern border (Mendoza-Cota & Pérez-Cruz, 2007). Despite the dispersion of these industries from the central zone, this region of the country continued with high participation in the number of jobs and added value at the national level, although with relatively lower growth rates than the regions above. The southern and south-eastern regions, the least urbanised in the country, have kept their participation in the national economy almost constant (Garza & Schteingart, 2010). The process of decentralising economic activities and employment has not only manifested itself at the regional and metropolitan level, although this continues to be its predominant outward sign (Trejo Nieto, 2019). Mexican regional urban' structure changes are significant in intermediate urban areas, which have had the highest demographic growth rates for almost two decades (Navarro et al., 2023). This process has strengthened the transition towards polycentrism at a regional and metropolitan scale.

2.3.Research hypothesis

Based on the literature review on the effect of agglomeration economies and regional urban structure on productivity, this paper defines three research hypotheses for Mexican urban regions:

- As demonstrated by most of the empirical studies described, the agglomeration economies generated by the size of the urban areas in demographic terms outweigh the disadvantages of density. Therefore:
  - H1. The size of the urban regional population has a positive and significant effect on productivity.
- Given that theoretical research refers to the benefits of agglomeration are increasingly correlated with polycentric regional urban structures, it is expected that:

- H2. A more polycentric regional urban structure has a positive and significant effect on the productivity of urban areas.

- As referred to in theory, the smaller urban areas take the greatest advantage of polycentricity because they probably achieve better functional relationships with other similar areas. In larger polycentric urban areas, the cores are big enough to operate independently. Thus:
  - H3. The positive effect of polycentrism on productivity decreases as the size of the urban regions increases in population.
- Given the wide territorial extension of Mexico and the heterogeneous distribution in the number, size and composition of urban regions in the country, as well as different dynamics of commercial integration with global markets, it is hypothesized that:
  - H4. There are significant differences in productivity produced by regional effects. In particular, the urban regions in the north of the country have higher productivity levels than those in the centre and south as a probable consequence of their economic integration with the North American market.
- The empirical evidence on the effects of the size of cities and their regional urban structure on productivity does not normally disaggregate results by sector. It is interesting for this research to know if the effects on productivity significantly differ between the two main economic sectors in Mexico: manufacturing and services. Therefore:
  - H5. The effect of urban region's size and structure on productivity significantly differs between the manufacturing and service sectors. In particular, a more significant effect of agglomeration economies and spatial structure is expected in the services sector, given its greater tendency towards spatial concentration.

The first hypothesis, while answering the first sub-question, represents a fundamental step to show the effect of agglomeration economies on productivity before delving into how Mexican urban regions' spatial structure affects this economic performance metric. Likewise, it allows to identify the effect of urban size on productivity and compare the results with previous works in Latin America and Mexico. The second hypothesis answers the central question of this research about the effect of polycentricity on productivity.

The third one addresses the second research sub-question and offers a specific answer for the Mexican context on the effect on the productivity of the interaction between the degree of polycentricity and urban size. The fourth answers the third sub-question of this work and refers to the differentiated effect that the specific characteristics of the different regions of the country could have on productivity beyond the size and spatial structure of the urban areas. The last hypothesis answers the fourth research sub-question on the effects of agglomeration economies and urban structure on the manufacturing and service sectors. Together, all these hypotheses let to achieve the objectives set for this thesis and generate new elements and suggestions for future research.

3. Operationalization and methodology

3.1.Measures of size and regional urban structure

This chapter presents the operationalisation of the main concepts used to identify the effect of size and regional urban structure on productivity. In addition, the data sources and variables of interest are described emphasising those used to deal with one of the main potential issues in this topic research: endogeneity in the relationship between size and regional urban structure with productivity.

To allow some comparability with previous studies, this research uses the same general methodological strategy as Meijers and Burger (2010) and Ouwehand, van Oort and Cortinovis (2022), who estimate the effect of size and polycentric structure on productivity in urban areas in the United States and Europe, respectively. Like them, this work opts for a morphological rather than a functional approach to the spatial structure of urban regions. This means that metrics on the size of the population and its distribution in the territory are used instead of indicators on the configuration of territorial hierarchies. The previous is because the information necessary to identify population and employment flows among regional urban areas is not generated with a sufficient level of representativeness, so it is required to create estimates from the expanded questionnaires of the population and housing censuses. This task is beyond the scope of this research (SEGOB et al., 2005). Unlike the reference studies mentioned, this work only covers two of the three urban dimensions analysed: population size and polycentricity, leaving out dispersion because this is, in practice, highly associated with polycentricity (Meijers & Burger, 2010). In the same line as these last two authors, this research considers the added value per worker or employed person as a productivity metric. It uses the population's size to directly estimate agglomeration's effect on Mexican urban areas' labour productivity.

3.1.1. Polycentricity-monocentricity dimension

Different measures are proposed in the literature to define the regional urban structure from a morphological point of view. Authors such as Galster et al. (2001) describe up to eight measures: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity. To precisely measure urban polycentricity, techniques such as remote sensing data are even used (Taubenböck et al., 2017). In their studies on productivity and urban form in Mexico, Montejano et al. (2020) make use of density, compactness and centrality to approximate the urban structure; in particular, they use uniformity metrics in the population distribution, such as the clustering index, to estimate the polycentricity of Mexican cities.

As Ouwehand et al. (2022) mention, including all these metrics in an econometric model is a complex task, mainly because some of these indicators require different precision details. Likewise, remote analysis techniques, although extremely precise, can only be used with relatively recent urban information, which means a methodological barrier for creating instrumental variables generated with data from the past. Due to the above, and to maintain comparability with previous studies, this paper considers the degree of polycentricity (i.e., the extent to which the regional urban population is split into different cities of a polynuclear area) as the main metric of regional urban structure.

The degree of polycentricity is estimated based on the rank-size distribution representing the balance and hierarchy between the urban nuclei that make up Mexico's urban or metropolitan areas, similar to the polycentric urban regions (PUR) defined by Meijers (2013). The adjustment proposed by Gabaix and Ibragimov (2011) is considered. These authors argue that the estimation of the distribution of the size of the cities through regression by ordinary least squares (OLS) is strongly biased in the case of small samples, as it is the case of this work. Therefore, including the term -1/2 reduces the bias in the estimation optimally, as shown in equation (1).

$$Ln\left(rank - \frac{1}{2}\right) = \alpha - \beta Ln(size) \qquad (1)$$

Additionally, as Ouwehand et al. (2022) proposed, equation (1) is transformed into equation (2) to interpret smaller β coefficients as a reflection of a more polycentric regional urban structure. In this formula, the coefficient β represents the degree of polycentricity-monocentricity within a PUR or metropolitan area. The greater the coefficient or slope of the regression, the greater the population predominance of a city over the rest within the urban region and, therefore, the greater the degree of monocentricity. Conversely, the lower the coefficient, the lower the hierarchy within the metropolitan area and, therefore, the higher the degree of polycentricity.

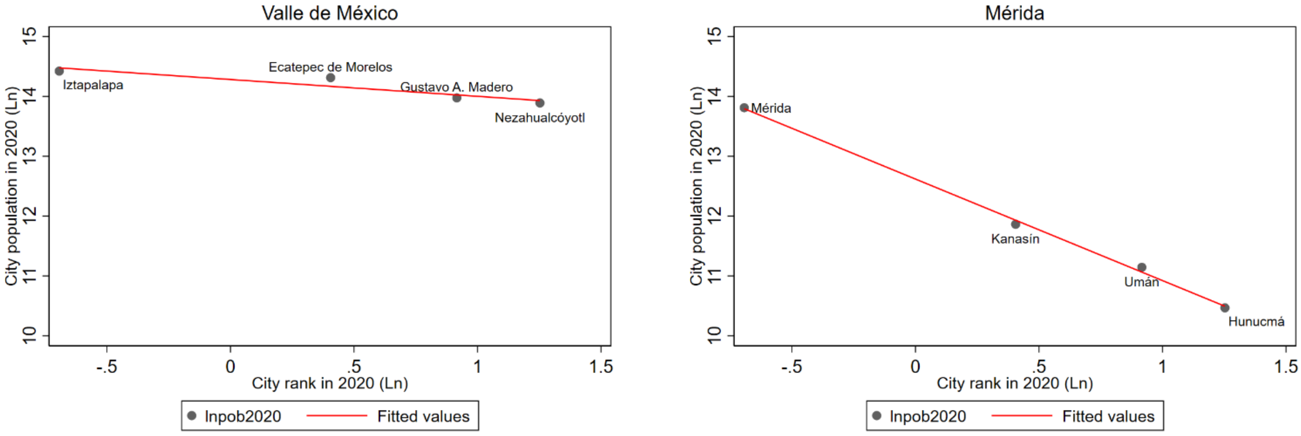
$$Ln(size) = \alpha + \beta Ln(rank - \frac{1}{2}) \qquad (2)$$

Some PUR or metropolitan areas are built up by a large number of city cores than others. Mexico City metro area, for example, includes 76 different urban municipalities while 16 of out 74 main metro areas in the country host only one city core. To prevent these differences from biasing the estimate of the degree of polycentricity, Meijers and Burger (2010) and Ouwehand et al. (2022) estimate the final degree of polycentricity by averaging the rank-size distribution for two, three, and four cities. This work uses this same criterion.

Although this number is still arbitrary, Meijers (2013) argues that defining a fixed number of city cores is more appropriate than indicating a minimum population threshold above which all cities in a PUR are included in the estimate or that the criterion of having several cities that represent a certain proportion of the population of the urban area. The latter indicates monocentricity or polycentricity by itself: the number of city cores included will be higher in the case of the polycentric regions and lower for monocentric areas. In the first case, a fixed threshold is inappropriate because, in highly populated metropolitan areas, a city of a specific size might be irrelevant in demographic terms, while it would be highly relevant in a less populated metro area.

Graphically, Figure 1Figure 1 shows the case of Valle de México (Mexico Valley), the capital metropolitan area, with a highly inside polycentric structure (more horizontal slope) and the case of Mérida, the biggest urban area in the southeast, with a predominantly monocentric regional urban structure (steepest slope).

Figure 1. Rank-size distribution in two Mexican urban regions. Valle de México (polycentric structure) and Mérida (monocentric structure)



Source: Own elaboration.

3.2.Other relevant measures

3.2.1. Variables that affect productivity

In addition to the effect of population size and regional urban structure, the literature recognises other factors that can positively affect labour productivity, the omission of which could generate estimates biased upwards that erroneously indicate a greater effect of agglomeration economies and polycentricity on productivity. To eliminate these biases, it is necessary to incorporate control variables in the estimated models.

One of these control variables is the availability of human capital, positively associated with both productivity and the size of cities (Cortinovis & van Oort, 2015; Glaeser & Resseger, 2010; Rauch, 1993). A second factor is physical capital, which explains a good part of the differences in productivity between economies (Mankiw et al., 1992; Romer, 1990). A third control element is the availability of infrastructure since it facilitates productive efficiency and persistently affects location patterns (Li, C. & Gibson, 2014; Melo et al., 2017). A fourth aspect affecting productivity is the labour density in urban areas, whose correlation with size, although positive, is not so high as to generate multicollinearity problems (Meijers & Burger, 2010; Meijers, 2013). Meijers and Burger (2010) use land availability per worker as an alternative way to estimate labour density since these metrics can be considered their inverse. Finally, certain macrogeographic characteristics specific to the region where urban areas are located also affect their productivity levels. These characteristics may be related to climatic or natural conditions, price levels and other socioeconomic aspects (Meijers & Burger, 2010; Ouwehand et al., 2022).

3.2.2. Endogeneity control

The literature on the effect of agglomeration economies on productivity recognises that this is not necessarily a unidirectional causal relationship; companies and workers can migrate to urban areas attracted, precisely, by the productivity advantages they observe in them. Therefore, agglomeration is the cause and consequence of productivity increases (Duranton & Puga, 2020; Rosenthal & Strange, 2004). Similarly, the regional urban structure can be an effect, and not an origin, of productivity: high land and housing prices, driven by high wages, encourage the relocation of people and companies to other cities in the urban region (Meijers & Burger, 2010). Omitting this simultaneous causal relationship can lead to biased and inconsistent estimates using the ordinary least squares (OLS) technique.

Various procedures exist to deal with this source of endogeneity and achieve efficient estimators. First, the creation of instrumental variables (IV): variables that, within the framework of this work, make it possible to explain the characteristics of size and regional urban structure but not the productivity levels. Usually, these instruments are created from historical measures of density or size (Ciccone & Hall, 1993) because the evidence indicates that the differences in these metrics persist over time, while the determinants of productivity have been completely transformed in the current context of economic globalization (Duranton & Puga, 2020; Scott & Storper, 2015). Second, the inclusion of fixed effects related to the location of urban areas to capture unobservable attributes that influence location patterns; however, this strategy is limited because changes in urban size and density are very slowly over time (Duranton & Puga, 2020). Third, the use of time-lagged variables to measure urban form (Duque et al., 2022), although this technique may be less effective also due to the slow process of change of the urban spatial structure. Other strategies, such as the generation of quasi-experimental scenarios (Greenstone et al., 2010) or more structured theoretical models applied to specific cases (Ahlfeldt et al., 2015), are much less used in practice due to their complexity and highly contextual application which reduces its degree of comparability with other studies.

As pointed out by Ciccone and Hall (1993), Meijers and Burger (2010), Combes et al. (2008) and Ouwehand et al. (2022), the most common procedure to eliminate simultaneous causation is the use of the two-stage least squares (TSLS) technique, which requires the creation of IVs. For this econometric method to work correctly, it is necessary, at least, to have as many instrumental variables (k) as endogenous regressors (m). This work has three potentially endogenous regressors: population size, degree of polycentricity and their interaction.

The instrumental variables must meet two conditions: relevance and exogeneity. An instrument is relevant when its variation is related to those of the endogenous coefficient. It is exogenous if it is not correlated with the error term in the regression with instrumental variables. The TSLS technique implies running a first regression that takes the endogenous variables as dependent variables and the proposed instruments as explanatory variables. The predicted values generated by this regression are used as new variables in a second regression. When IVs are relevant and exogenous, the TSLS technique produces more accurate estimators than OLS-based regressions (Stock & Watson, 2020).

3.3. Variables and data sources

This work uses three main sources of information to generate the variables of interest. First, the population and housing censuses of 1930 and 2020 that contain demographic information on the country's urban and rural localities for those years. Second, the 2019 Economic Census, which has disaggregated data on employment, production, added value and other indicators of the economic activity of formal companies in the country. Third, urban information from the 2018 National Urban System (UNS) that defines the 74 metropolitan areas of the country. The National Institute of Statistics and Geography (INEGI) generated the population and economic censuses, while the UNS information comes from federal government agencies. Other sources of information were used to create specific variables in the model, as described in the following subsections.

3.3.1. Main variables

3.3.1.1. Labor productivity

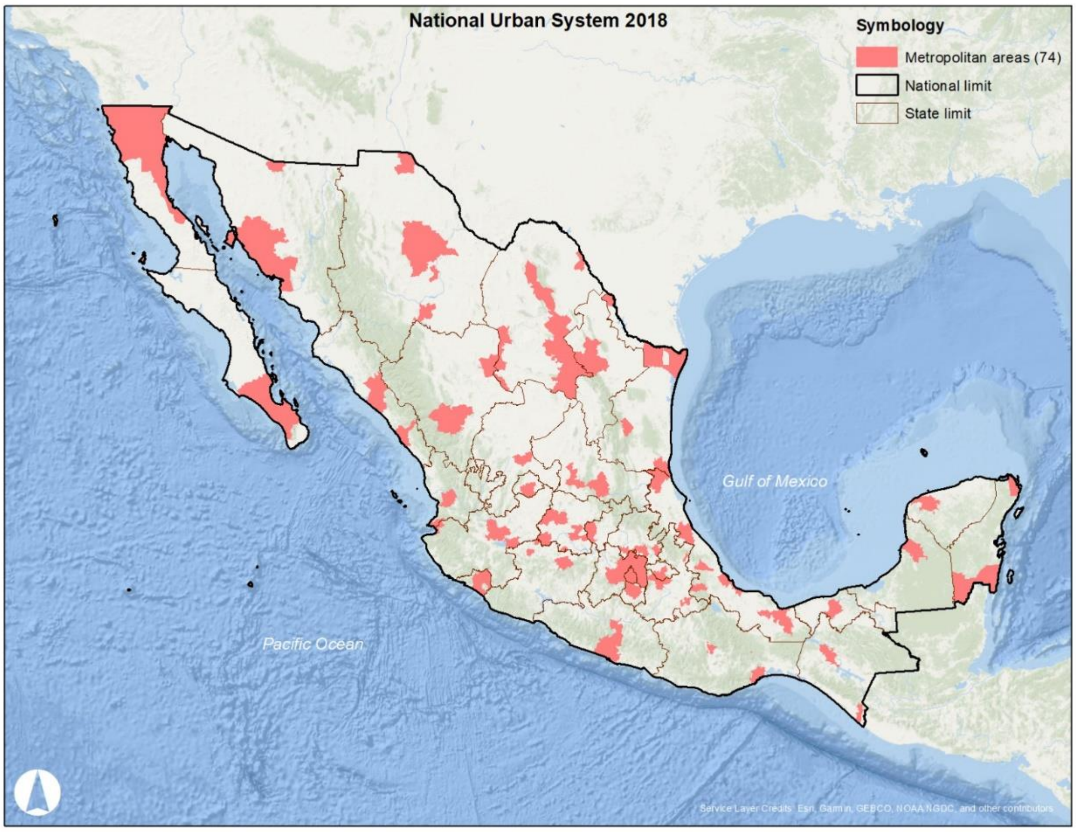
The economic performance metric used in this work is labour productivity resulting from dividing the gross census-added value (in millions of pesos) by the number of employed persons. Value added is the value of production incorporated by the transformation process involving the employed personnel, physical capital, and the organisation of production factors. Employed persons are employees who work in companies or economic units during a reference period and depend on the said company, contractually or not.

Both variables were obtained from the 2019 Economic Censuses (INEGI, 2020a). The information has a geographical disaggregation level at a national, state, municipal, and sectoral level up to the class of economic activity level (six digits of disaggregation), following the criteria of the North American Industrial Classification System (SCIAN). The estimate of labour productivity was generated with information at the subsector level (3 digits) and municipal geographic scale.

3.3.1.2. Size and polycentricity

To estimate the population size of urban regions, the definition of the 74 metropolitan areas of the country and the 417 municipalities or city cores that integrate them was used, according to UNS 2018 (SEGOB et al., 2018). The population of each city core was updated using data from the 2020 Population and Housing Census (INEGI, 2020b). Map 1 shows the territorial distribution of the 74 metropolitan areas of the country used in this research.

Map 1. Metropolitan areas in Mexico



Source: SEGOB et al. (2018).

The degree of urban polycentricity is estimated from equation (2) based on information from the 2020 Population and Housing Census. The variables used in this work result from the average rank-size distributions for each urban area's two, three and four main cities, following the criteria defined by Meijers and Burger (2010) and Ouwehand et al. (2022).

3.3.2. Control variables

To reduce the bias due to omitted variables and more precisely estimate the effect of size and polycentricity on urban labour productivity, this paper considers other variables that may influence the observed productivity levels:

- Human capital. Two metrics are used as proxies: proportion of the population aged 18 and over with post-basic education (with completed primary and secondary) and average years of schooling. Meijers and Burger (2010) use the proportion of the population aged 25 and over with a university degree as a proxy for human capital, while Ouwehand et al. (2022) estimate this indicator based on the proportion of the economically active population (15 to 65 years old) with tertiary education. On the other hand, Botev et al. (2019) point out that the number of years of schooling is a metric typically used in productivity studies. The information for both variables come from the 2020 Population and Housing Census.
- Physical capital. Following Ouwehand et al. (2022), gross fixed capital formation (i.e: the value of fixed assets purchased by the economic unit minus the value of fixed asset sales) is used. This information comes from the 2019 Economic Census.
- Land availability. Based on Meijers and Burger (2010), the square kilometres per worker within the urban region is used as an inverse measure of labour density. This indicator, expressed in natural logarithm, has a correlation of -0.636 with the natural logarithm of population size, which, although moderately high, does not represent a source of multicollinearity.
- Availability of infrastructure. Two metrics are used. On the one hand, a dummy that indicates the presence of a deep-water port less than 50 kilometres away from the urban area, whose source of information is the National Port System 2022 (Ministry of the Navy, 2022). On the other hand, the urban road density that results from dividing the length of roads by the urbanised area. This indicator is an infrastructure proxy to facilitate the transport of people and goods (UN-Habitat, 2017) and is highly associated with urban productivity (Duque et al., 2022). The information comes from the UN-Habitat City Prosperity Index (2018).
- Regional division. The literature suggests including regional effects to moderate the relationship between agglomeration and regional urban structure on labour productivity. This paper considers six macro-regions: 1) centre, 2) centre-west, 3) northwest, 4) north-centre, 5) northeast and 6) south-southeast, as indicated by the National Land Management Strategy 2020-2040 (SEDATU, 2021). However, given that some of these macro-regions contain ten or fewer urban areas, it was decided to integrate the macro-regions 3), 4) and 5) into a single one and fusion the macro-regions 6) and 1) centre. In this way, three final macro-regions are obtained: 1) centre-south, 2) centre-west and 3) north. The country's central-south region is taken as a reference because it contains the Mexican capital. Table 1 shows the socioeconomic characteristics of each of the six original macro-regions.

Table 1. Main socioeconomic characteristics by macro-region

Variable	Macro-region						Total
	Centre	CW	NW	NC	NE	SS	
Urban regions (#)	24	19	9	5	10	7	74
Regional urban area (km2)	39,492.2	33,145.3	90,946.4	34,171.5	59,241.7	23,301.1	280,298.1
Population 2020	37,274,241	16,239,841	6,858,003	3,506,237	11,472,297	4,813,889	80,164,508
%Pop +18 post-basic education	54.3%	50.9%	53.8%	50.6%	52.2%	54.5%	53.1%
Years of schooling	10.56	10.38	10.61	10.60	10.64	10.53	10.54
Productivity per worker (MXN)	$405,917	$319,249	$292,894	$270,227	$453,811	$216,044	$368,599
Added value (Mill-MXN)	$3,770,750	$1,422,118	$562,203	$288,144	$1,550,549	$237,582	$7,831,346
Employees	9,289,451	4,454,578	1,919,477	1,066,303	3,416,732	1,099,689	21,246,230
Capital per worker (MXN)	$41,565	$18,411	$10,782	$11,352	$30,993	$11,320	$29,147
Land per worker (m2)	4,251.3	7,440.7	47,380.8	32,046.7	17,338.7	21,188.8	13,192.8
Road density (km/km2)	2.14	1.10	0.25	0.41	0.56	0.54	0.72

Notes:

- CW (Centre-west), NW (Northwest), NC (North-centre), NE (Northeast), SS (South-southeast).
- Mill-MXN: Millions of Mexican pesos.

Source: Own elaboration.

3.3.3. Instrumental variables

To clarify the direction of causality between the analysis variables, it is proposed to use up to five instruments to have an over-identified model where the number of instrumental variables exceeds the number of endogenous regressors (Stock & Watson, 2020). Firstly, following Meijers and Burger (2010) and Ouwehand et al. (2022), historical information on the population size of cities is used. Specifically, information is taken from the Fifth Population Census (INEGI, 1934) with demographic data from 1930 to estimate the size and degree of polycentricity of the 74 urban areas analysed. It is considered that the urban population in that year is correlated with the current size and structure of the metropolitan areas but not with their productivity levels.

Ouwehand et al. (2022) mention that another instrumental variable is the use of current data on the surface of urban areas since these delimitations are based on exogenous criteria (historical processes or political-administrative definitions) and because the borders tend to be stable in time. In this research, the total surface of metropolitan areas is used as the third instrumental variable, whose source of information is the 2020 Population and Housing Census.

Given the specific characteristics of the urbanisation process in Mexico, two additional instruments are proposed. On the one hand, the linear distance from urban areas to Mexico City urban region, which generates 17% of the country's GDP, occupies only 0.1% of the territory (World Bank, 2020) and concentrates 17.3% of the national population and 23% of the urban system population (SEGOB et al., 2018). Historically, the Mexican capital has brought together the main economic, political and social activities and has determined a pattern of productive and demographic concentration in the country's central zone, integrating different urban areas into what can be called the megalopolitan region of Mexico City (Garza & Schteingart, 2010).

On the other hand, it is proposed to use a dichotomous variable that indicates when the urban area is located on the border with the United States. As mentioned in the previous chapter, the economic liberalisation and trade opening with the North American region have favoured the growth of urban regions in the northern areas of the country. Economic integration across national borders is associated with higher spatial concentrations in countries like Mexico due to lower transportation costs and better connectivity (Grover et al., 2022; World Bank, 2020). The distance between urban areas was calculated based on the 2020 Population and Housing Census, while the border criterion is based on the Free Zone of the Northern Border Programme (Ministry of Economy, 2020). Table 2 shows the main descriptive statistics of the described variables.

Table 2. Descriptive statistics of main variables (n=74)

Variable	Mean	SD	Min	Max
Labour productivity (Ln)	-1.319	.456	-3.194	-.185
Population 2020 (Ln)	13.221	.977	11.597	16.898
Degree of polycentricity 2020 (Ln)	.035	.675	-1.212	1.56
Year of education (Ln)	2.313	.086	2.081	2.437
% pop +18y with post basic educ (%)	49.3	79.0	25.8	63.0
% pop +18y with post basic educ (Ln)	-.722	.178	-1.354	-.462
Capital per worker (Ln)	-4.194	.811	-5.741	-.796
Land per worker (Ln)	-4.054	1.13	-6.668	-1.347
Road density (Ln)	-.258	.972	-2.612	1.606
Port (d)	.203	.405	0	1
Centre-south (d)	.419	.497	0	1
Centre-west (d)	.257	.44	0	1
North (d)	.324	.471	0	1
Population 1930 (Ln)	9.143	1.04	5.194	11.175
Degree of polycentricity 1930 (Ln)	-.036	.588	-1.387	1.6
Urban region area (Ln)	7.685	1.05	5.478	9.904
Distance to Mexico City (Ln)	5.763	2.999	-18.421	7.74
Border with US (d)	.122	.329	0	1

Notes: dummy variables are marked with a ‘d’ and variables in logs are marked with ‘Ln’. Other metrics are in parentheses.

Source: Own elaboration.

3.4.Conceptual econometric model

The model used to test the four hypotheses of this work is based on the one defined in Meijers and Burger (2010), so that the results obtained can be compared to some extent with their findings. The authors use a Cobb-Douglas-type production function with constant returns to scale, as shown in equation (3a).

$$Q = AK^{\kappa}L^{\lambda}H^{\sigma}M^{\mu}N^{\nu} \tag{3a}$$

Where:

- Q is the economy's nominal output produced by combining all production factors
- K is the physical capital
- L is the labour
- H is the human capital
- M is the materials or inputs
- N is the land urban area
- A is a measure of Total Factor Productivity (TFP), which integrates various exogenous effects on the production function, including size and polycentricity, but excludes the rest of the production factors mentioned.
- $\kappa+\lambda+\sigma+\mu+\nu=1$

Subsequently, Equation (3a) is expressed in terms per worker and logarithmically transformed to obtain (3b):

$$Ln(q) = Ln(A) + \kappa\text{Ln}(\text{k}) + \sigma\text{Ln}(\text{h}) + \mu\text{Ln}(\text{m}) + \nu\text{Ln}(\text{n}) \tag{3b}$$

Where:

- q is labour productivity measured as the gross census value added by the number of people employed in an urban area
- k is the physical capital per worker
- h is the human capital per worker or average education
- n is the land urban area per worker
- A is a measure of TFP

Since the value added (Q) results from subtracting the intermediate consumption of inputs from the total gross production, M is not considered in the model estimates. A following transformation of equation (3b) results from integrating a set of independent variables X with parameters β that estimate the effect of urban size and regional urban structure on productivity and form part of the production function through a higher value of A (Broersma & Oosterhaven, 2009; Meijers & Burger, 2010). This vector includes the control variables related to the availability of infrastructure. Human capital, physical capital and land availability per worker are explicitly shown in the model. Land availability can be understood as the inverse of labour density, so including both variables in the model would generate a multicollinearity problem. Finally, regional effects (r_j) are also considered to account for other differences in productivity and moderate the effect of size and degree of polycentricity on the dependent variable. This way, a stochastic linear form is obtained, represented by equation (3c) for each urban area j.

$$Ln(q) = \beta_0 + \sum_j \beta_{j+1}\,\text{Ln}(X_j) + \kappa\text{Ln}(\text{k}) + \sigma\text{Ln}(\text{h}) + \nu\text{Ln}(n) + r_j + \epsilon_j \tag{3c}$$

This equation could be estimated using ordinary least squares; however, since the OLS technique does not consider the possible simultaneous causality between variables, the two-stage least squares estimation is implemented too.

4. Empirical results

This chapter describes the main results of the models proposed in the previous section. First, the results generated by the regressions based on ordinary least squares (OLS) are presented, including the one that considers the interaction between the two main independent variables of interest: the size of the urban region and its degree of polycentricity. The aggregate results, as well as for the manufacturing and service sectors, are presented in this section to identify the differentiated effects of the spatial structure on productivity in these two large sectors of the Mexican economy. The second subsection presents the results obtained using the two-stage least square setting (TSLS) technique to establish causality between the variables involved. All model specifications consider control factors such as the population's educational level, the availability of physical capital and land per worker, as well as the existence of infrastructure and dummies for macro-regional effects.

As shown in Appendix 1, a high correlation (>95%) was identified between the natural logarithm of the number of years of schooling and the natural logarithm of the percentage of the population with post-basic education, so after running some preliminary models, the first variable was omitted from the base regressions presented in this work. After that, the Variance Inflation Factor (VIF) test, which determines the strength of the correlation of independent variables, did not show values greater than 10, the threshold from which the presence of severe collinearity is considered (Garcia et al., 2019). Based on this, it was unnecessary to omit any other variable from the models (see results of the VIF test in Appendix 2).

Although no significant heteroskedasticity problems were observed, according to the White test and Breusch–Pagan/Cook–Weisberg test for heteroskedasticity (see results in Appendix 2), the regression results consider robust standard errors. The dependent variable, labour productivity, and all the independent variables, except the dummies, are expressed in natural logarithms to achieve a better fit in the model and normalize the distribution of the data, which makes it possible to correct biases when variables reach very large values (Stock & Watson, 2020). The total number of observations corresponding to the urban areas of interest is 58 instead of 74 because monocentric urban regions are not considered since, by definition, it is not possible to estimate their degree of polycentricity.

4.1.Results based on OLS

4.1.1. OLS general model

To show the effects of the population size of the urban region and its degree of polycentricity on labour productivity, four main models are presented in this section. The first incorporates only the population size of urban areas in 2020; the second takes into account the degree of polycentricity estimated from the range-size distribution of the cities in each urban region; the third includes both variables simultaneously, and the fourth incorporates the interaction effect between size and the degree of polycentricity.

As **Error! Reference source not found.** shows, holding everything else constant, there is a positive and significant association at 10% between the logarithm of the population size of the urban region and the logarithm of labour productivity. In the model with all the variables incorporated, it is observed that the regions with twice the population achieve labour productivity that is 11.1% higher[1]. This agglomeration effect is within the range indicated by other studies in Latin America (Grover, Lall, & Timmis, 2021).

On the other hand, the effect of the degree of polycentricity oscillates between almost zero and negative, which is particularly clear when the interaction term is incorporated; however, the relationship is not statistically significant in any model, nor is the effect of the interaction variable. In terms of the differentiated effects by region, it is observed that only in the second specification is there a positive and significant effect at 10% for the northern macro-region. This area observes labour productivity levels 22% higher than the central-south macro-region, the reference category.

Although it is not of particular interest for the analysis, the only variable that shows a robust significant association (at 1%) with labour productivity is the natural logarithm of physical capital per worker; if this factor increases by 1%, an increase in productivity of around 0.4% would be expected regardless of the model considered. No other variable is significant.

Table 3. Ordinary least squares (OLS) results. Models with population size, degree of polycentricity and interaction between both

	Labour productivity (Ln)			
Variables	(1) Size	(2) Polycentricity	(3) Size & Poly	(4) Size x Poly
Population 2020 (Ln)	0.117*		0.120*	0.111*
	(0.059)		(0.060)	(0.065)
Degree of polycentricity 2020 (Ln)		0.004	-0.018	-0.346
		(0.064)	(0.062)	(0.675)
Size x Polycentricity				0.023
				(0.048)
% pop +18y with post basic educ (Ln)	0.087	0.251	0.068	0.094
	(0.282)	(0.265)	(0.292)	(0.302)
Capital per worker (Ln)	0.399***	0.402***	0.400***	0.394***
	(0.051)	(0.051)	(0.051)	(0.053)
Land per worker (Ln)	0.072	-0.015	0.070	0.068
	(0.055)	(0.045)	(0.055)	(0.057)
Urban road density (Ln)	-0.225	-0.159	-0.243	-0.305
	(0.191)	(0.207)	(0.200)	(0.224)
Port (d)	-0.078	-0.094	-0.071	-0.052
	(0.106)	(0.111)	(0.107)	(0.111)
Centre-west (d)	0.133	0.142	0.133	0.153
	(0.096)	(0.100)	(0.098)	(0.104)
North (d)	0.139	0.220*	0.138	0.149
	(0.115)	(0.115)	(0.116)	(0.120)
Constant	-0.297	0.834	-0.311	-0.059
	(1.015)	(0.696)	(1.025)	(1.147)
Observations	58	58	58	58
R-sq	0.712	0.657	0.714	0.706
Adjusted R-squared	0.665	0.601	0.660	0.643

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[1] In this model, strictly, it is not correct to interpret the population size coefficient in isolation since there is an interaction variable, although it is not significant.

Source: Own elaboration.

4.1.2. OLS models for manufacturing and services sectors

Given that one of this work's hypotheses is based on identifying specific effects of agglomeration economies and the spatial structure on labour productivity in different productive sectors, we proceeded to generate OLS regressions for manufacturing and service activities in Mexico, following the same general considerations of the models described in the previous section. The results for the manufacturing sector are shown in **Error! Reference source not found.**, and for the service sector, in Table 5.

4.1.2.1. Manufacturing sector (OLS)

In the case of the manufacturing sector, no significant effects of population size on labour productivity were found, although the sign and magnitude of the coefficients are not as expected. It is worth remembering that, in the case of Mexico, Quintero & Roberts (2018) show that the productivity premiums generated by agglomeration economies were insignificant (0.3%), while Montejano et al. (2020) and Monkkonen et al. (2020) find a negative effect of urban density on labour productivity in the manufacturing sector. So, these results do not seem atypical for the Mexican case, specifically in the manufacturing sector.

On the other hand, the natural logarithm of the degree of polycentricity negatively affects labour productivity in the sector. However, this relationship is only significant (at 5%) when the interaction effect is considered, which has a statistical significance of 10%. This means that regions with similar degrees of polycentricity but with different population sizes have different levels of labour productivity; particularly, the degree of polycentricity of urban regions impacts productivity indirectly but positively as population size increases. Alternatively, the interaction effect indicates that holding the population constant, there are greater agglomeration economies when urban regions are more polycentric, a result opposite to that observed by Meijers and Burger (2010) and Ouwehand et al. (2022).

The models have no differentiated regional effects, but a positive and highly significant association (at 1%) is observed between the natural logarithm of capital per worker and labour productivity. The coefficient of this variable exceeds in absolute value when finding for the general case: a 1% increase in the availability of capital would increase productivity per worker by around 0.51%, which indicates the strong association between both factors of production in this sector. No other variable is significant.

4.1.2.2. Services sector (OLS)

In contrast to the results observed in the manufacturing sector, in the services sector, there is a positive and highly significant association (at 1%) between the population size of urban regions and labour productivity. Keeping everything else constant, when the population of a region doubles, increases between 21% and 22% are observed in sectoral productivity, values that almost double those observed for the general model that considers all sectors of the economy. The final value of the effect of demographic size on productivity must also consider the coefficient of the interaction variable, whose effect is positive and significant at 10%.

As in the previous case, there is a negative and significant effect (at 5%) of the degree of polycentricity on labour productivity only when the interaction variable is incorporated, although the absolute values of the coefficients are lower than those observed for the manufacturing sector. This means that the magnitude of agglomeration economies when the polycentricity of urban regions increases but demographic size remains constant, is comparatively smaller in the services sector, perhaps because industry benefits more from mutual spillovers and supply streams between neighbouring cities taking advantages from 'borrowed size' (Glaeser et al., 2016; Meijers et al., 2016); on the contrary, the service sector benefits from relatively less polycentric urban patterns given their greater tendency towards spatial concentration (Grover et al., 2022).

The models show that the centre-west and north regions reach higher levels of productivity in the services sector, compared to the centre-south region, possibly as a consequence of the very low levels of productivity of the urban regions of the southeast, which considered together with those of the central macro-region. These regional effects are statistically significant at 1%, although the values of the coefficients are highly variable, depending on the observed model.

A positive and significant effect (at 1%) of the availability of capital on labour productivity is also observed; however, the absolute values of the coefficients are lower than in the previous case because the service sector is less intensive in physical capital. Likewise, the urban road density shows a negative and significant coefficient (between 1% and 10%, depending on the model) that could reflect the existence of agglomeration diseconomies generated, for example, by the traffic or the low road infrastructure quality. The rest of the variables do not show stability in the significance and magnitude of their coefficients.

Table 4. OLS results for manufacturing sector

	Labour productivity (Ln)			
Variables	(1m) Size	(2m) Polycentricity	(3m) Size & Poly	(4m) Size x Poly
Population 2020 (Ln)	-0.008 (0.093)		0.001 (0.098)	-0.122 (0.098)
Degree of polycentricity 2020 (Ln)		-0.096 (0.107)	-0.096 (0.111)	-2.275** (1.115)
Size x Polycentricity				0.155* (0.080)
% pop +18y with post basic educ (Ln)	-0.350 (0.514)	-0.370 (0.437)	-0.374 (0.543)	-0.147 (0.514)
Capital per worker (Ln) | manufacturing	0.511*** (0.054)	0.507*** (0.054)	0.506*** (0.055)	0.516*** (0.052)
Land per worker (Ln) | manufacturing	-0.021 (0.072)	-0.041 (0.063)	-0.041 (0.074)	-0.098 (0.070)
Urban road density (Ln)	0.477 (0.358)	0.379 (0.372)	0.377 (0.380)	0.003 (0.383)
Port (d)	-0.294 (0.200)	-0.235 (0.203)	-0.235 (0.207)	-0.176 (0.196)
Centre-west (d)	-0.255 (0.171)	-0.258 (0.173)	-0.258 (0.176)	-0.174 (0.172)
North (d)	-0.024 (0.181)	-0.034 (0.183)	-0.035 (0.186)	0.001 (0.176)
Constant	-0.202 (1.715)	-0.142 (1.111)	-0.154 (1.768)	2.464 (1.849)
Observations	58	58	58	58
R-sq	0.722	0.719	0.716	0.761
Adjusted R-squared	0.677	0.674	0.663	0.710

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Own elaboration.

Table 5. OLS results for services sector

	Labour productivity (Ln)			
	(1s)	(2s)	(3s)	(4s)
Variables	Size	Polycentricity	Size & Poly	Size x Poly
Population 2020 (Ln)	0.216***		0.222***	0.212***
	(0.043)		(0.044)	(0.042)
Degree of polycentricity 2020 (Ln)		-0.078	-0.047	-0.907**
		(0.049)	(0.044)	(0.436)
Size x Polycentricity				0.063*
				(0.031)
% pop +18y with post basic educ (Ln)	0.028	0.487**	0.015	0.026
	(0.201)	(0.206)	(0.207)	(0.195)
Capital per worker (Ln) | services	0.187***	0.190***	0.184***	0.166***
	(0.049)	(0.054)	(0.050)	(0.048)
Land per worker (Ln) | services	-0.032	-0.139***	-0.034	-0.031
	(0.039)	(0.038)	(0.040)	(0.037)
Urban road density (Ln)	-0.264*	-0.524***	-0.317**	-0.404***
	(0.135)	(0.160)	(0.143)	(0.143)
Port (d)	0.094	0.115	0.105	0.105
	(0.067)	(0.077)	(0.069)	(0.065)
Centre-west (d)	0.197***	0.319***	0.204***	0.242***
	(0.068)	(0.077)	(0.069)	(0.068)
North (d)	0.368***	0.541***	0.368***	0.366***
	(0.092)	(0.100)	(0.093)	(0.087)
Constant	-3.448***	0.027	-3.411***	-3.150***
	(0.910)	(0.688)	(0.922)	(0.890)
Observations	58	58	58	58
R-sq	0.805	0.691	0.804	0.832
Adjusted R-squared	0.773	0.641	0.767	0.796

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Own elaboration.

4.2.Results based on TSLS

Although the results generated based on OLS suggest some significant correlations between the effect of demographic size and polycentricity on labour productivity, especially in the case of the service sector, it is necessary to clarify the meaning of this relationship since, theoretically, there is a bidirectional association between these variables, as described in section 3.2.2. To ensure that the effect goes from spatial factors towards labour productivity and not in the opposite direction, it is necessary to use the two-stage least squares (TSLS) technique, which requires the creation of instrumental relevant (non-weak) and exogenous (valid) variables.

In section 3.3.3, the use of five instruments was justified for the three endogenous variables of interest. However, after testing, the linear distance from urban areas to Mexico City and the Border dummy were discarded as relevant variables because, in the first-stage regression they presented values less than 10 in the F-statistic. This threshold is a simple rule of thumb typically used in econometrics that defines when an instrumental variable is not strong enough to be considered in the analysis (Stock & Watson, 2020).

Even though having three IVs would be enough to reach an identified model in which the number of instruments equals the number of endogenous regressors, it was decided to generate an additional instrumental variable that would allow estimating an over-identification test to empirically assess exogeneity (validity) of the instruments used, as suggested by Ouwehand et al. (2022). This new instrument results from running separate first-stage regressions that take the endogenous variables of size and polycentricity as dependent variables, after which their predicted values are saved as new variables. Subsequently, an interaction term is generated based on these predicted values, which is used as an instrument for the endogenous interaction term, as in Bloom et al. (2013). In this way, in each specification of the models, it was possible to have more instruments than endogenous independent variables and to generate the over-identification tests.

The results of the relevance and validity tests are presented in the lower part of tables 6, 7 and 8 with the Wu-Hausman F-test and Durbin Chi-Square test that evaluate if there is an endogenous relationship between the variables of interest. The implications of these three test categories are discussed in the next section with the results of the general TSLS model, while the first-stage regression results are presented in Appendix 3.

4.2.1. TSLS general model

According to the results of Table 6, there is a positive effect of demographic size on labour productivity; however, this relationship is only significant at 10% when the interaction term with the degree of polycentricity is taken into account, which implies that the size of the urban region is not a strong predictor of productivity. As in the OLS model, neither the urban polycentricity nor the interactive effect are significant. In terms of regional effects, in model (9), it is possible to observe that the northern macro-region has a labour productivity 23.3% higher than the central-south zone, an effect that is significant at 10%.

Once again, capital per worker shows a strong positive association with productivity, with a significant relationship at 1%. In models (9), (10) and (11), a negative and significant effect is observed at 10% for the dummy Port, which indicates that the urban regions close to this type of infrastructure have labour productivity between 33% and 36% less than the rest; however, given the magnitude of the coefficient, this variable may be capturing other characteristics of urban areas that make them comparatively less productive, for which further research is necessary in this regard. No other effect is significant.

On the other hand, the F-statistics results from the first-stage regressions are sufficiently large and significant at 1%, which means that the instruments used are strong or relevant to the model. Likewise, the p-values of the Sargan and Basmaan over-identification tests indicate that, except for model (9), the rest of the models are correctly specified and, therefore, the instruments are valid or exogenous. The Durbin and Wu-Hasmann tests indicate that the variables of population size, polycentricity, and the interaction term are exogenous to the model, so the OLS estimators are more efficient than the estimators obtained through TSLS (Stock & Watson, 2020). The result of this test, although contrary to theory, coincides with the findings of Meijers and Burger (2010) because spatial restructuring and changes in population density and distribution patterns are a very long-term process (Duque et al., 2022; Duranton & Puga, 2020; Lee, B. & Gordon, 2007).

Table 6. Two-stage least square setting (TSLS) results. Models with population size, degree of polycentricity and interaction between both

	Labour productivity (Ln)			
	(8)	(9)	(10)	(11)
Variables	Size	Polycentricity	Size & Poly	Size x Poly
Population 2020 (Ln)	0.176		0.157	0.224*
	(0.110)		(0.109)	(0.122)
Degree of polycentricity 2020 (Ln)		0.216	0.164	2.969
		(0.141)	(0.125)	(2.368)
Size x Polycentricity				-0.199
				(0.160)
% pop +18y with post basic educ (Ln)	-0.103	0.449	0.057	0.038
	(0.357)	(0.318)	(0.378)	(0.452)
Capital per worker (Ln)	0.288***	0.307***	0.275***	0.291***
	(0.066)	(0.068)	(0.069)	(0.071)
Land per worker (Ln)	0.126	0.050	0.136	0.144
	(0.110)	(0.063)	(0.107)	(0.107)
Urban road density (Ln)	-0.391	-0.197	-0.249	0.152
	(0.299)	(0.300)	(0.305)	(0.533)
Port (d)	-0.302	-0.360*	-0.331*	-0.357*
	(0.186)	(0.209)	(0.186)	(0.188)
Centre-west (d)	0.052	0.061	0.022	-0.096
	(0.086)	(0.103)	(0.100)	(0.158)
North (d)	0.137	0.233**	0.144	0.133
	(0.113)	(0.093)	(0.108)	(0.124)
Constant	-0.951	1.017	-0.954	-2.761
	(1.723)	(0.972)	(1.780)	(2.467)
Relevance				
First-stage F-statistic	596.578***		438.191***	280.366***
First-stage F-statistic		18.764***	13.184***	16.562***
First-stage F-statistic				19.613***
Exogeneity				
Durbin (score) chi2(1)	.4470	1.3645	1.3193	3.9867
	(p = 0.5038)	(p = 0.2428)	(p = 0.5170)	(p = 0.2629)
Wu-Hausman F test	.3728	1.1564	.5354	1.08255
	(p = 0.5443)	(p = 0.2876)	(p = 0.5891)	(p = 0.3664)
Validity				
Sargan chi2(1)	.3788	3.094	.06064	.01112
	(p = 0.5383)	(p = 0.0786)	(p = 0.8055)	(p = 0.9160)
Basmann chi2(1)	.3155	2.7048	.04919	.0088
	(p = 0.5743)	(p = 0.1000)	(p = 0.8245)	(p = 0.9252)
Observations	58	58	58	58
R-sq	0.433	0.377	0.421	0.314
Adjusted R-squared	0.340	0.275	0.312	0.168

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Own elaboration.

4.2.2. TSLS models for manufacturing and services sectors

As with the OLS models, we proceeded to analyse the effects of agglomeration and polycentricity on the productivity of the manufacturing and service sectors to identify specific differences between them. The results for the manufacturing sector are presented in Table 7 and for the service sector in Table 8.

4.2.2.1. Manufacturing sector (TSLS)

In the case of manufacturing, no significant effects of population size or degree of polycentricity on productivity were found. Likewise, it is observed that in all the models, the macro-region centre-west has significantly lower levels of productivity than the region centre-south. This association is significant at 10% and relatively stable in the first three models: between 34% and 38; however, in the specification that includes the interaction term, the coefficient in absolute value practically doubles the previous ones, in addition to the fact that the significance increases to 5%. The only significant and stable associations in terms of the magnitude of their coefficients were found in the capital per worker (positive and significant at 1%) and deep port (negative and significant at 5%) variables.

The F-statistics results from the first-stage regressions are sufficiently large and significant at 1%, except the value associated with the polycentricity variable in the third model, whose value is 7.662, so most of the instruments used are relevant to the model. The p-values of the Sargan and Basmaan tests show that the models are correctly specified, and the instruments are valid. The Durbin and Wu-Hasmann tests indicate that the variables of interest cannot be treated as endogenous.

4.2.2.2. Services sector (TSLS)

As in the OLS case, there is a positive and significant association at 1% between the demographic size of urban regions and their labour productivity in the services sector. All else equal, the effect ranges from 23% to 27%. Likewise, the effect of the degree of polycentricity on productivity is negative in all specifications but only significant at 5% when the interaction term is considered, which is also significant at 5%.

As previously mentioned, the sign of the interaction means that agglomeration economies have a greater effect on productivity when the polycentricity of urban regions increases while maintaining constant population size. Another way of understanding this interaction is that regions with similar degrees of polycentricity but more populated achieve higher productivity levels. This indirect effect is additional to that generated by the demographic size itself.

Unlike the OLS model, no statistically significant regional effects are observed, and the negative effect of urban road density disappears. Capital per worker has a positive and significant effect (at 1%) on labour productivity, although the absolute values of the coefficients are lower than in the previous case.

Regarding the tests of the instrumental variables, the F-statistics are large and significant at 1% in all cases, so the instruments used are relevant. The p-values of the Sargan and Basmaan tests indicate that the (10s) and (11s) models are correctly specified, but not the (9s) model, in which the test results indicate that the instruments are not valid. The results in the model (8s) are mixed, although the Sargan test is at the limit of significance. The Durbin and Wu-Hasmann tests indicate that the variables of interest are not endogenous.

Table 7. TSLS results for manufacturing sector

	Labour productivity (Ln)			
	(8m)	(9m)	(10m)	(11m)
Variables	Size	Polycentricity	Size & Poly	Size x Poly
Population 2020 (Ln)	0.187		0.144	0.326
	(0.179)		(0.185)	(0.226)
Degree of polycentricity 2020 (Ln)		0.399	0.270	6.836
		(0.293)	(0.244)	(4.410)
Size x Polycentricity				-0.463
				(0.297)
% pop +18y with post basic educ (Ln)	-1.778	-0.992	-1.502	-1.547
	(1.113)	(0.950)	(1.123)	(1.228)
Capital per worker (Ln) | manufacturing	0.448***	0.441***	0.439***	0.417***
	(0.081)	(0.082)	(0.083)	(0.092)
Land per worker (Ln) | manufacturing	0.035	-0.016	0.033	0.049
	(0.154)	(0.105)	(0.155)	(0.164)
Urban road density (Ln)	0.668	1.022	0.898	1.775*
	(0.715)	(0.722)	(0.707)	(1.045)
Port (d)	-0.950**	-1.010**	-0.992**	-0.991**
	(0.473)	(0.461)	(0.462)	(0.449)
Centre-west (d)	-0.338*	-0.373*	-0.375*	-0.651**
	(0.179)	(0.198)	(0.192)	(0.278)
North (d)	0.085	0.138	0.114	0.143
	(0.221)	(0.207)	(0.210)	(0.233)
Constant	-4.451	-2.476	-4.311	-9.022*
	(3.665)	(2.403)	(3.774)	(4.960)
Relevance				
First-stage F-statistic	66.779***	11.308***	40.854***	86.548***
First-stage F-statistic			7.662***	23.750***
First-stage F-statistic				26.236***
Exogeneity				
Durbin (score) chi2(1)	2.2681	.7818	2.3881	3.1902
	(p = 0.1321)	(p = 0.3766)	(p = 0.3030)	(p = 0.3632)
Wu-Hausman F test	1.9535	.6558	.9877	.8537
	(p = 0.1686)	(p = 0.4220)	(p = 0.3802)	(p = 0.4722)
Validity				
Sargan chi2(1)	.0137	.6551	.7029	.3998
	(p = 0.9067)	(p = 0.4183)	(p = 0.4018)	(p = 0.5272)
Basmann chi2(1)	.0114	.5483	.5766	.3193
	(p = 0.9151)	(p = 0.4590)	(p = 0.4477)	(p = 0.5720)
Observations	58	58	58	58
R-sq	0.366	0.363	0.368	0.230
Adjusted R-squared	0.262	0.259	0.249	0.066

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Own elaboration.

Table 8. TSLS results for services sector

	Labour productivity (Ln)			
	(8s)	(9s)	(10s)	(11s)
Variables	Size	Polycentricity	Size & Poly	Size x Poly
Population 2020 (Ln)	0.253***		0.266***	0.231***
	(0.044)		(0.047)	(0.057)
Degree of polycentricity 2020 (Ln)		-0.032	-0.107	-1.775**
		(0.115)	(0.077)	(0.856)
Size x Polycentricity				0.118**
				(0.060)
% pop +18y with post basic educ (Ln)	0.137	0.655***	0.034	0.013
	(0.183)	(0.244)	(0.180)	(0.209)
Capital per worker (Ln) | services	0.213***	0.306***	0.225***	0.197***
	(0.049)	(0.066)	(0.051)	(0.058)
Land per worker (Ln) | services	0.070	-0.060	0.066	0.055
	(0.074)	(0.072)	(0.076)	(0.079)
Urban road density (Ln)	-0.060	-0.203	-0.167	-0.385
	(0.176)	(0.232)	(0.188)	(0.243)
Port (d)	-0.009	-0.009	0.015	0.029
	(0.096)	(0.108)	(0.102)	(0.116)
Centre-west (d)	0.085	0.133	0.099	0.180
	(0.098)	(0.115)	(0.102)	(0.122)
North (d)	0.113	0.267	0.106	0.128
	(0.178)	(0.192)	(0.192)	(0.198)
Constant	-3.780***	0.368	-3.694***	-2.896***
	(0.863)	(0.571)	(0.863)	(1.100)
Relevance				
First-stage F-statistic	331.868***	22.570***	292.022***	215.707***
First-stage F-statistic			21.977***	16.630***
First-stage F-statistic				20.876***
Exogeneity				
Durbin (score) chi2(1)	.4224	.0587	1.669	3.281
	(p = 0.5157)	(p = 0.8086)	(p = 0.4341)	(p = 0.3503)
Wu-Hausman F test	.3521	.0486	.6814	.8795
	(p = 0.5557)	(p = 0.8264)	(p = 0.5110)	(p = 0.4591)
Validity				
Sargan chi2(1)	2.7656	18.9672	1.0136	1.4263
	(p = 0.0963)	(p = 0.0000)	(p = 0.3140)	(p = 0.2324)
Basmann chi2(1)	2.4034	23.3247	.8360	1.1597
	(p = 0.1211)	(p = 0.0000)	(p = 0.3605)	(p = 0.2815)
Observations	58	58	58	58
R-sq	0.366	0.363	0.368	0.230
Adjusted R-squared	0.262	0.259	0.249	0.066

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Own elaboration.

5. Conclusions and final remarks

In the urban economics literature, an extensive repertoire demonstrates the positive effects and limits of agglomeration in different dimensions of the socioeconomic performance of cities, particularly in their economic productivity, based on the trade-off between economies and diseconomies of agglomeration, a balance that explains why cities do not increase infinitely.

In recent decades, the accelerated process of global urbanization, and the trend of various economic activities to relocate to other urban areas as a strategy to reduce agglomeration diseconomies, have generated significant changes in the structure of cities that have forced to think about the city as a regional phenomenon that manifests itself in increasingly extensive and polycentric urban patterns. The formation of networks of polynuclear urban regions implies that agglomeration economies are not restricted to a single urban centre but have a broader regional scope in which several sub-centres share agglomeration advantages. In this way, in addition to agglomeration, the type of urban structure, more or less polycentric, appears as a second dimension of analysis that can impact the economic performance of cities.

Empirical studies on agglomeration economies are practically unanimous regarding the positive association between urban size and density and productivity gains. In contrast, the results of the urban structure are inconclusive on the final effect of polycentricity on productivity, especially when the size of urban regions is considered, generating non-constant effects. These ambivalent findings make it interesting to analyse more specific cases because the empirical evidence is highly contextual and depends on sector and country-specific characteristics, as well as econometric models used.

In this context, and based on a morphological approach to urban structure, this work empirically sought to identify the spatial effects of agglomeration and polycentricity on the economic performance of Mexican urban regions approximated by labour productivity in order to contribute to the generation of evidence for Latin American countries, for which there is much less availability of empirical studies than for the global north nations. An additional contribution of this work is that it generates results not only at the aggregate level but also for the manufacturing and service sectors, which makes it possible to identify specific effects of agglomeration and urban structure.

To achieve the objective, the studies by Meijers and Burger (2010) and Ouwehand, van Oort and Cortinovis (2022), which estimates the effect of size and polycentric structure on productivity in the United States and Europe, were taken as key references. The productivity metric is the same implemented by Meijers and Burger (2010): the value added per worker. The main dependent variables used were population size to estimate the effect of agglomeration economies and the degree of polycentricity resulting from the range-size distribution of city centres within each urban region. The following controls were incorporated to eliminate biases due to omitted variables: educational level of the population, availability of physical capital and land per worker, urban road density, proximity to the deep port, and dummies for macro-regional effects. All continuous variables were expressed in natural logarithms, so the effects of the independent variables on the dependent one can be understood as elasticities.

To generate the estimates, two statistical techniques were used: OLS and TSLS, which allows for defining the direction of causality between the variables involved, since the theory indicates that there is an endogenous relationship between productivity and size and spatial structure. The results obtained are translated into five main findings, which are contrasted one by one with the initial hypotheses.

According to the relevance and validity tests presented for the TSLS models, it is possible to point out that, in general, the instruments used in the specifications are strong (relevant) and valid or exogenous. However, the Durbin and Wu-Hasmann tests indicate that the variables of population size, degree of polycentricity, and the interaction term cannot be considered endogenous, contrary to what would be expected according to the theory. Therefore, although the instruments are relevant and exogenous, the estimates by OLS are more efficient than the estimators obtained by TSLS.

5.1.Main findings

Finding 1. Positive and significant effects of agglomeration on productivity are mainly observed in the service sector but not in manufacturing.

The size of the urban agglomeration, measured from the number of inhabitants, has a positive and highly significant effect (at 1%) on labour productivity only in the case of the services sector, both in the OLS and TSLS models. The effect is also positive and significant in the OLS model for the aggregate case, although the statistical significance is only 10%. No significant effects of agglomeration on productivity are observed for the manufacturing sector.

The magnitude of the effect of agglomeration on productivity for the aggregate case is found in the range of studies carried out in the Latin American context; however, the value of the coefficient in the services sector is considerably high. Previous studies had already found marginal effects of agglomeration on productivity in the Mexican case (Quintero & Roberts, 2018) and even negative ones for the case of the manufacturing sector (Monkkonen et al., 2020; Montejano et al., 2020), possibly As a consequence of the accelerated process of urban expansion in Mexican cities driven, partly, by the placement of manufacturing industries on the outskirts of main urban regions.

Based on these findings, hypothesis H1 is only true for the service sector and partially true for the aggregate model only when OLS estimates are used.

Finding 2. The degree of polycentricity has a negative effect on productivity when analysing results by sector, not in the aggregated.

In the aggregate model, the degree of polycentricity does not significantly affect labour productivity. In other words, a more evenly distributed urban population across cities does not affect productivity for the Mexican urban regions. However, in the OLS models, there is a negative and significant effect (at 5%) of polycentricity on productivity only when the interaction term is incorporated into the models. This association and significance are maintained for the service sector in the TSLS models but disappear for manufacturing.

This service sector finding contradicts Meijers and Burger (2010), who found a positive association between polycentric urban structure and productivity but agrees with Ouwehand et al. (2022), who show a negative relationship between these variables.

Based on the above, H2 is not met as expected. In the Mexican case, one explanation for the fact that polycentricity is not significant in the aggregate model lies in the enormous differences in performance between the country's urban regions. Consequently, the impact of polycentricity could be balanced between regions with very high performances and others with very low performances. The negative signs observed for specific sectors are a consequence of the prevalence of a highly monocentric spatial pattern in Mexico, where, in addition, the patterns of population and industrial deconcentration observed in recent decades have not been matched by an equivalent deconcentration of infrastructure and of physical capital (Mendoza-Cota & Pérez-Cruz, 2007; Navarro et al., 2023).

Finding 3. In the service sector, the effect of polycentricity increases when the size of urban regions grows. For the manufacturing sector, mixed results are observed.

In the aggregate model, the interaction term between size and polycentricity has no significant effect. In the case of the services sector, the interaction term has a positive effect in both the OLS and TSLS models. In contrast, this effect is only significant (and also positive) for the manufacturing sector in the OLS model.

This positive association indicates that by keeping the degree of polycentricity constant, cities with more inhabitants will reach higher levels of labour productivity. The higher value of the coefficient in the manufacturing sector reflects that this industry benefits more from sharing the advantages of agglomeration with other urban regions ('borrowed size') compared to the service sector, which obtains greater benefits from less polycentric urban patterns because it tends to a higher spatial concentration. This result of the interaction term is contrary to the findings of Meijers and Burger (2010) and Ouwehand et al. (2022).

Based on the above, H3 is not met because the evidence shows that, in the Mexican case, larger urban regions derive more advantages from polycentricity, achieving better functional relationships with other similar areas. Smaller urban regions fail to generate polycentric networks that increase productivity.

Finding 4. In Mexico, there are no significant and stable differences in the aggregate labour productivity of the different macro-regions. The differences found depend highly on the specifications used and the sector analysed.

In the aggregate models, both by OLS and by TSLS, no significant and stable differences are observed in labour productivity between macro-regions of the country. However, in the OLS models for the service sector, it is possible to identify higher productivity levels in the Centre-west and North macro-regions concerning the Centre-south region. The regional effects are statistically significant at 1% and reach up to 24.2% for the central-western zone and 36.6% for the northern zone in the model that incorporates all the variables of interest.

On the other hand, in the TSLS model, it is only possible to identify significant differences in productivity in the manufacturing sector and in the case of the Centre-west region. In this situation, the differences in productivity are negative concerning the Centre-South region and reach a value of up to 65% in the most complete model. It is a coefficient that almost doubles the observed values for the three models without the interaction term.

Due to the above, it is not possible to support H4 since, although there are some significant differences in productivity between macro-regions, these depend on the sector analysed and are not always significant in the case of the northern zone.

Finding 5. The effect of agglomeration and the degree of polycentricity vary significantly between the manufacturing and service sectors, where the greatest effects of size and urban structure are reflected.

Based on previous findings, it is possible to point out that the effects of agglomeration and spatial structure on productivity are substantially different, depending on the sector analysed.

In the case of the services sector, the effect of population size on productivity is highly significant for all specifications; however, this relationship is not present in the case of manufacturing (finding 1). On the other hand, the effect of polycentricity on productivity is negative in the case of the services sector but only significant when the interaction term is considered. This is true for both the OLS and TSLS models. Regarding the manufacturing sector, there are mixed results, but the only ones that are significant (and negative) are the models generated with OLS (finding 2). The coefficient of the degree of polycentricity in absolute value is higher for the manufacturing sector than for the services sector.

Regarding the interaction term, the services sector shows a positive and significant effect in both specifications (OLS and TSLS), while this only occurs in the manufacturing sector when OLS runs regressions (finding 3). The interaction effect is greater for the case of manufacturing when the OLS models are compared.

Therefore, H5 is partially met. On the one hand, as expected, the greater spatial concentration of the services sector favours it is benefiting to a greater extent than agglomeration economies, but, on the other hand, the effect of the degree of polycentricity in absolute value and of the interaction term they are greater for the case of the manufacturing sector when their coefficients are significant.

5.2.Future research agenda

This work identified the effects of agglomeration economies and the degree of polycentricity on the economic performance of urban regions. The empirical analysis contributes to closing the gaps in the evidence available on these effects in Latin America, particularly in Mexico. Of course, considering this study's time and scope limitations, much more research is still needed to refine the findings obtained.

Firstly, the results are based on a cross-sectional analysis for the year 2020. The economic information sources used could be capturing specific temporary effects, such as those generated by the Coronavirus pandemic or the entry into force of the new free trade agreement between Mexico, the United States and Canada (USMCA) signed in 2020, but pre-agreed since 2018 (Mexican Senate & Ministry of Economy, 2021). Longitudinal studies that consider sufficiently wide time windows would allow for greater robustness in the analyses and identify significant changes in spatial concentration patterns associated with changes in productivity.

On the other hand, although the variable used in this work as a proxy for agglomeration economies is a widely accepted metric (Meijers, 2013), future studies could use estimates of total factor productivity (TFP), considered a superior measure of economic performance (Cortinovis & van Oort, 2019; Ouwehand et al., 2022).

Mexico is an urban country, mainly metropolitan, but at the same time, highly dispersed (Trejo Nieto, 2019). The national urban system considers 327 conurbations and urban localities with more than 15,000 inhabitants, in addition to the 74 metropolitan areas analysed in this work, whose incorporation in subsequent studies would substantially modify the indicators of polycentricity and productivity. However, achieving this requires the integration of much more territorially disaggregated databases and generating productivity metrics at the local level, which would involve more sophisticated techniques such as remote analysis.

Although this work generated estimates for the manufacturing and service sectors, refining the statistical information would facilitate to analyse of specific subsectors, such as those focused on knowledge-intensive services. This would make it possible to generate empirical evidence of the association between spatial concentration and creative services or highly demanding skills. Of course, refining the control measures, especially human capital and infrastructure, would allow to specify the effect of these variables on economic performance and, therefore, reduce possible biases of size and spatial structure on productivity.

From an urban and regional planning perspective, it is important to remember that the results obtained are based on a morphological approach to the spatial structure of urban regions, so they should not be understood as the effects on the productivity of functional relationships between metropolitan areas. Incorporating a functional approach requires generating metrics on the flows of people, capital, goods and services to understand how these interactions define urban hierarchies.

With these considerations in mind, the empirical results of this work could serve to feed national policies with an explicit spatial focus that seeks, on the one hand, to achieve a more balanced population distribution in the territory and, on the other, to improve the economic performance of urban regions closing the gaps of territorial inequality that prevail in Mexico.

Achieving a more balanced and convergent development path requires emphasizing the close relationship between urbanization, productivity and economic growth. For this, awareness is needed about the importance of place-based policies that consider the geographical characteristics of the urban system as a critical element to increase the performance of the Mexican economy as a whole in the context of economic globalization and consolidation of trade liberalization with North America.

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Appendix 1

A1. Correlation matrix

Table A-1. Correlation matrix of all variables included in the estimations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
(1) Lab prod (Ln)	1.000																		
(2) Pop 2020 (Ln)	0.294	1.000																	
(3) Poly 2020 (Ln)	0.136	0.035	1.000																
(4) Size x Poly	0.152	0.085	0.994	1.000															
(5) Year educ (Ln)	0.191	0.616	-0.263	-0.225	1.000														
(6) %Pop educ (Ln)	0.137	0.592	-0.270	-0.228	0.956	1.000													
(7) Capital pw (Ln)	0.528	0.222	0.117	0.137	0.146	0.199	1.000												
(8) Land pw (Ln)	0.038	-0.636	-0.118	-0.140	-0.297	-0.282	0.068	1.000											
(9) Urban road (Ln)	-0.135	0.184	-0.368	-0.327	0.339	0.371	-0.121	0.018	1.000										
(10) Port (d)	-0.032	-0.172	0.091	0.087	-0.126	0.004	0.402	0.286	-0.067	1.000									
(11) Centre south (d)	-0.086	0.035	0.009	0.017	0.033	0.210	0.116	-0.238	-0.259	0.188	1.000								
(12) Centre-west (d)	-0.163	-0.086	0.133	0.109	-0.238	-0.335	-0.312	-0.057	0.124	-0.159	-0.648	1.000							
(13) North (d)	0.293	0.055	-0.163	-0.145	0.231	0.123	0.212	0.359	0.178	-0.051	-0.493	-0.343	1.000						
(14) Pop 1930 (Ln)	0.086	0.002	0.103	0.097	-0.106	-0.179	-0.088	0.201	-0.005	-0.177	-0.403	0.349	0.098	1.000					
(15) Poly 1930 (Ln)	0.147	-0.111	0.478	0.480	-0.239	-0.254	-0.082	0.153	-0.215	-0.238	0.156	-0.089	-0.091	0.332	1.000				
(16) Urban area (Ln)	0.411	0.511	-0.133	-0.099	0.457	0.401	0.333	0.312	0.280	0.077	-0.362	-0.114	0.577	0.221	-0.035	1.000			
(17) Distance (Ln)	-0.150	-0.438	-0.381	-0.444	-0.075	-0.089	-0.133	0.383	0.000	0.131	-0.259	0.088	0.219	-0.012	-0.459	-0.061	1.000		
(18) Border (d)	0.085	0.051	-0.196	-0.195	0.008	-0.050	0.140	-0.003	0.033	-0.119	-0.226	-0.157	0.457	-0.188	-0.278	0.131	0.118	1.000	
(19) Size x Poly (predicted)	0.204	0.125	0.700	0.709	-0.297	-0.329	0.180	-0.190	-0.460	0.116	0.031	0.158	-0.220	0.266	0.679	-0.084	-0.628	-0.217	1.000

Source: Own elaboration.

Appendix 2

A2. Tests for multicollinearity and heteroskedasticity

Chart A-1. Variance Inflation Factor (VIF) before and after excluding natural logarithm years of schooling

Before

Variable	VIF	1/VIF
% pop +18y with post basic educ (Ln)	25.930	0.039
Year of education (Ln)	25.440	0.039
North (d)	2.390	0.418
Centre-West (d)	2.040	0.489
Port (d)	1.490	0.672
Urban road density (Ln)	1.400	0.714
Land per worker (Ln)	1.360	0.736
Capital per worker (Ln)	1.230	0.810
Mean VIF	7.660	

After

Variable	VIF	1/VIF
North (d)	1.530	0.652
Centre-West (d)	1.520	0.656
% pop +18y with post basic educ (Ln)	1.430	0.698
Land per worker (Ln)	1.310	0.765
Urban road density (Ln)	1.290	0.775
Port (d)	1.260	0.792
Capital per worker (Ln)	1.230	0.810
Mean VIF	1.370	

Source: Own elaboration.

Chart A-2. White test and Breusch–Pagan/Cook–Weisberg test for heteroskedasticity

White's test

H0: Homoskedasticity

Ha: Unrestricted heteroskedasticity

chi2(31) = 31.43

Prob > chi2 = 0.4449

Cameron & Trivedi's decomposition of IM-test

Source	chi2	df	p
Heteroskedasticity	31.430	31	0.445
Skewness	7.930	7	0.339
Kurtosis	1.480	1	0.224
Total	40.830	39	0.390

Breusch–Pagan/Cook–Weisberg test for heteroskedasticity

Assumption: Normal error terms

Variable: Fitted values of lnprodtot_sun

H0: Constant variance

chi2(1) = 0.06

Prob > chi2 = 0.8048

Source: Own elaboration.

Appendix 3

A3.1 First-stage regression results for the TSLS estimations (all sectors)

A3.1.1 Results for two endogenous variables (size and polycentricity). All sectors

	Dependent (endogenous) variable	
Variables	Size 2020	Polycentricity 2020
Population 1930 (Ln)	0.071**	0.126
	(0.027)	(0.098)
Regional urban area (Ln)	0.906***	-0.117
	(0.035)	(0.111)
Degree polycentricity 1930 (Ln)	-0.018	0.606***
	(0.045)	(0.151)
%Pop +18 post basic educ (Ln)	-0.093	-0.254
	(0.147)	(0.574)
Capital per worker (Ln)	0.003	0.070
	(0.035)	(0.082)
Land per worker (Ln)	-0.809***	-0.158
	(0.029)	(0.114)
Urban road density (Ln)	0.061	-0.668**
	(0.096)	(0.325)
Port (d)	-0.057	0.562**
	(0.078)	(0.240)
Centre-west (d)	-0.246***	0.444**
	(0.053)	(0.213)
North (d)	-0.440***	0.387
	(0.093)	(0.237)
Constant	2.209***	0.406
	(0.497)	(2.004)
First-stage F-statistic	438.191***	13.184***
Observations	58	58
R-sq	0.985	0.514
Adjusted R-squared	0.981	0.411

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Own elaboration.

A3.1.2. Results for three endogenous variables (size, polycentricity and dispersion). All sectors

	Dependent (endogenous) variable		
Variables	Size 2020	Polycentricity 2020	Size x Polycentricity
Population 1930 (Ln)	0.079**	0.156*	2.513**
	(0.031)	(0.090)	(1.169)
Regional urban area (Ln)	0.894***	-0.163	-2.364
	(0.042)	(0.143)	(1.967)
Degree polycentricity 1930 (Ln)	-0.316	-0.595	-17.515
	(0.373)	(1.476)	(20.920)
Size x polycentricity (predicted)	0.040	0.161	3.482
	(0.050)	(0.199)	(2.853)
%Pop +18 post basic educ (Ln)	-0.078	-0.193	-2.440
	(0.153)	(0.607)	(8.259)
Capital per worker (Ln)	0.001	0.061	0.875
	(0.034)	(0.081)	(1.091)
Land per worker (Ln)	-0.799***	-0.117	-1.539
	(0.036)	(0.145)	(2.011)
Urban road density (Ln)	0.046	-0.729**	-8.690*
	(0.101)	(0.346)	(4.694)
Port (d)	-0.060	0.549**	7.476**
	(0.078)	(0.233)	(3.056)
Centre-west (d)	-0.240***	0.472**	6.160**
	(0.055)	(0.211)	(2.870)
North (d)	-0.430***	0.428*	6.154*
	(0.095)	(0.244)	(3.239)
Constant	2.262***	0.623	1.800
	(0.535)	(2.173)	(31.039)
First-stage F-statistic	280.366***	16.562***	19.613***
Observations	58	58	58
R-sq	0.985	0.521	0.521
Adjusted R-squared	0.981	0.406	0.406

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Own elaboration.

A3.2. First-stage regression results for the TSLS estimations (manufacturing sector)

A3.2.1. Results for two endogenous variables (size and polycentricity). Manufacturing sector

	Dependent (endogenous) variable	
Variables	Size 2020	Polycentricity 2020
Population 1930 (Ln)	0.117	0.205*
	(0.106)	(0.109)
Regional urban area (Ln)	0.856***	-0.161
	(0.112)	(0.128)
Degree polycentricity 1930 (Ln)	-0.120	0.528***
	(0.133)	(0.167)
%Pop +18 post basic educ (Ln)	0.862**	-0.037
	(0.355)	(0.573)
Capital per worker (Ln) | manufacturing	-0.043	-0.026
	(0.043)	(0.048)
Land per worker (Ln) | manufacturing	-0.541***	-0.041
	(0.062)	(0.098)
Urban road density (Ln)	0.123	-0.768**
	(0.228)	(0.342)
Port (d)	0.036	0.591**
	(0.233)	(0.269)
Centre-west (d)	-0.364**	0.408*
	(0.175)	(0.220)
North (d)	-1.091***	0.340
	(0.269)	(0.284)
Constant	4.608***	0.489
	(1.429)	(2.033)
First-stage F-statistic	40.854***	7.662***
Observations	58	58
R-sq	0.890	0.487
Adjusted R-squared	0.867	0.378

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Own elaboration.

A3.2.2. Results for three endogenous variables (size, polycentricity and dispersion). Manufacturing sector

Variables	Dependent (endogenous) variable Size 2020	 Polycentricity 2020	 Size x Polycentricity
Population 1930 (Ln)	0.168**	0.235**	3.556***
	(0.077)	(0.094)	(1.238)
Regional urban area (Ln)	0.753***	-0.221	-3.096
	(0.096)	(0.138)	(1.850)
Degree polycentricity 1930 (Ln)	-3.359***	-1.389	-27.974*
	(0.912)	(1.172)	(16.307)
Size x polycentricity (predicted)	0.439***	0.260	4.791**
	(0.121)	(0.160)	(2.266)
%Pop +18 post basic educ (Ln)	0.896***	-0.017	-0.005
	(0.322)	(0.561)	(7.477)
Capital per worker (Ln) | manufacturing	-0.037	-0.022	-0.354
	(0.037)	(0.047)	(0.619)
Land per worker (Ln) | manufacturing	-0.493***	-0.013	-0.214
	(0.055)	(0.103)	(1.377)
Urban road density (Ln)	-0.024	-0.855**	-10.532**
	(0.225)	(0.342)	(4.632)
Port (d)	-0.001	0.569**	7.943**
	(0.173)	(0.242)	(3.180)
Centre-west (d)	-0.265*	0.467**	6.106**
	(0.148)	(0.213)	(2.856)
North (d)	-0.913***	0.445	6.427*
	(0.206)	(0.284)	(3.742)
Constant	4.986***	0.713	2.465
	(1.179)	(1.994)	(28.182)
First-stage F-statistic	86.548***	23.750***	26.236***
Observations	58	58	58
R-sq	0.914	0.508	0.509
Adjusted R-squared	0.894	0.390	0.391

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Own elaboration.

A3.3 First-stage regression results for the TSLS estimations (services sector)

A3.3.1 Results for two endogenous variables (size and polycentricity). Services sector

	Dependent (endogenous) variable	
Variables	Size 2020	Polycentricity 2020
Population 1930 (Ln)	0.134***	0.149*
	(0.038)	(0.087)
Regional urban area (Ln)	0.829***	-0.176
	(0.044)	(0.113)
Degree polycentricity 1930 (Ln)	-0.078	0.609***
	(0.050)	(0.136)
%Pop +18 post basic educ (Ln)	-0.491***	-0.179
	(0.156)	(0.584)
Capital per worker (Ln) | services	-0.026	0.208**
	(0.046)	(0.100)
Land per worker (Ln) | services	-0.748***	-0.088
	(0.043)	(0.106)
Urban road density (Ln)	-0.018	-0.849***
	(0.108)	(0.312)
Port (d)	-0.121	0.593***
	(0.077)	(0.216)
Centre-west (d)	-0.249***	0.386**
	(0.066)	(0.190)
North (d)	-0.155*	0.382
	(0.082)	(0.256)
Constant	2.848***	2.360
	(0.703)	(2.343)
First-stage F-statistic	292.022***	21.977***
Observations	58	58
R-sq	0.980	0.543
Adjusted R-squared	0.976	0.446

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Own elaboration.

A3.3.2. Results for three endogenous variables (size, polycentricity and dispersion). Services sector

Variables	Dependent (endogenous) variable		
	Size 2020	Polycentricity 2020	Size x Polycentricity
Population 1930 (Ln)	0.132***	0.153*	2.476**
	(0.038)	(0.089)	(1.169)
Regional urban area (Ln)	0.832***	-0.180	-2.612
	(0.044)	(0.138)	(1.867)
Degree polycentricity 1930 (Ln)	0.032	0.447	-3.447
	(0.482)	(1.697)	(24.272)
Size x polycentricity (predicted)	-0.015	0.022	1.603
	(0.064)	(0.229)	(3.303)
%Pop +18 post basic educ (Ln)	-0.495***	-0.172	-2.066
	(0.162)	(0.615)	(8.382)
Capital per worker (Ln) | manufacturing	-0.022	0.202	2.791
	(0.053)	(0.127)	(1.685)
Land per worker (Ln) | manufacturing	-0.750***	-0.085	-1.070
	(0.045)	(0.125)	(1.717)
Urban road density (Ln)	-0.015	-0.853**	-10.423**
	(0.111)	(0.324)	(4.392)
Port (d)	-0.120	0.591***	8.075***
	(0.079)	(0.216)	(2.839)
Centre-west (d)	-0.253***	0.391*	5.040*
	(0.068)	(0.201)	(2.743)
North (d)	-0.158*	0.388	5.565
	(0.083)	(0.271)	(3.638)
Constant	2.866***	2.333	25.227
	(0.715)	(2.295)	(30.890)
First-stage F-statistic	215.707***	16.630***	20.876***
Observations	58	58	58
R-sq	0.980	0.543	0.542
Adjusted R-squared	0.975	0.434	0.433

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Own elaboration.

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