Local spatial-autocorrelation and urban ring identification in Mexico City's Regional Belt

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Abstract. We explore the urban structure of eight metropolitan areas that surround Mexico City, forming its regional belt, by identifying spatial clusters within metropolitan areas with a regionally standardized local-spatial-autocorrelation procedure. The analysis reveals clear concentric urban ring patterns around the city centers; these patterns have different levels of complexity, suggesting diverse stages of evolution of the urban structure of these metropolitan areas.

Key words: Spatial autocorrelation, urban rings, urban structure.

Autocorrelación espacial-local y la identificación de contornos urbanos en la Corona Regional de la Ciudad de México

Resumen. Se exploró la estructura urbana de las ocho áreas metropolitanas que forman la Corona Regional de la Ciudad de México, mediante la identificación de clusters espaciales basados en un algoritmo de autocorrelación espacial regionalmente estandarizado. El análisis revela claros patrones de contornos urbanos con diferente grado de complejidad alrededor de las ciudades centrales, lo que sugiere distintas etapas en la evolución de las áreas metropolitanas.

Palabras clave: Autocorrelación espacial, contornos urbanos, estructura urbana.

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INTRODUCTION

Identification of urban structure consists of the recognition of urban patterns and clusters of contiguous areas that share distinct characteristics. In the monocentric city, these clusters appear as urban rings surrounding the city center. The formation of urban rings is associated with urban growth, but most importantly, it is a reflection of city dynamics and structure. Even in non-monocentric cities, ring patterns around nodes, centers and subcenters are common. In all cases the key component is, of course, distance. In an optimal model, rings may occur at different hierarchical scales from the neighborhood to the region.

Critics of both the economic model (Alonso, 1964; Mills, 1972; Muth, 1969) and the cultural model (Burgess, 1924) of the monocentric city have suggested that cities have evolved into more complex urban structures. As early as 1939, Hoyt (1939) suggested the model of sectors, and six years later Harris and Ullman (1945) developed the multiple nuclei model suggesting a diversity of possible patterns of urban stucture.

Since the 1990s, attention has shifted to the recognition of subcenters, i.e. small areas that represent economic nodes and transportation destinations for residents within a city, under the assumption that the monocentric model is insufficient to explain modern city dynamics. However, the subcenter approach ignores any parts of the city that are not economic subcenters and it fails to classify them.

In contrast, an advantage of the urban ring and urban sector approach is that it classifies all parts of a city. Urban rings and sectors can be useful tools with which to compare cities and their stages of evolution. Within cities, urban rings can be useful spatial units of analysis to compare different parts of a city across different periods of time.

The purpose of this article is to analyze differences in the stages of evolution of the urban structure of the eight metropolitan areas that surround Mexico City and form its Regional Belt.[1] By

urban structure we mean the spatial distribution of population and economic activity within each metropolitan area. This working definition of urban structure has been widely used (Small and Song, 1992; Giuliano and Small, 1993; McMillen, 2003; Suárez and Delgado, 2009).

We suggest a method of analysis through which spatial clusters within metropolitan areas can be identified with a regionally standardized local-spatial-autocorrelation procedure. With this method, we are able to find urban ring structures around eight cities, each with distinct socioeconomic characteristics. Owing to the characteristics of city centers and the size and number of urban rings, the analysis suggests different stages of metropolitan development for each city. Ring structures vary from simple center-periphery structures to more complex inter-metropolitan multi-centered hierarchical structures.

The rest of this article comprises five sections. The first section is a literature review of methods of ring identification and uses of urban rings, as well as a review of their critics. We present our study area in the second section with the aid of population and employment statistics from 1990 to 2004 for each metropolitan area. The third section describes our urban ring identification methodology. Next, we present the urban ring structure results for each city, and socioeconomic descriptives for the rings of each city. Finally, we present our conclusions and questions for further research.

LITERATURE REVIEW

It is widely agreed that the growth of cities implies changes in urban structure, including the arrangement of city functions and specialization, as well as socioeconomic segregation (Orfield, 2002; Suárez-Villa, 1988; Giersch, 1984). It is also agreed that as cities grow they eventually become polycentric, and that the monocentric model is simply not able to explain today's cities (Giuliano and Small, 1991; Giuliano and Small, 1993; Glaeser and Kohlhase,

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[1] The term Mexico City's Regional Belt (*Corona Regional de la Zona Metropolitana de la Ciudad de México*) comes from the work of Delgado (1998) who identified the limits of this region in terms of a Functional Regional Urban System.

2003; Small and Song, 1992). The debate has shifted towards techniques of identifying urban economic subcenters and the efficiency of modern polycentric cities (Cervero and Wu, 1998; Levinson and Kumar, 1994).

Polycentricity has been classified as an advanced stage in cities (Anas *et al.*, 1998; Helsley and Sullivan, 1991). Cities may evolve into polycentric structures as they grow. City subcenters, besides sharing the advantages of agglomeration economies that characterize central cities (Chinitz, 1965; Mills, 1972), represent a more efficient urban arrangement (Aguilar and Alvarado, 2005). According to classic urban economic theory, polycentric structures are achieved when city size is such that transportation costs may be minimized by the formation of subcentral employment areas, thus generating greater urban efficiency (Fujita, 1999).

Recent studies cast doubt on the idea of polycentricity and suggest a simultaneous dispersal and nucleation of economic activity that leads to a chaotic urban growth (Shearmur *et al.*, 2007). For Los Angeles, CA, which for decades has been the prototype of the polycentric city, Gordon and Richardson (1996) have reported a declining number of subcenters. Other research suggests that metropolitan edges may be blurring (Lang and Knox, 2009) and explores the existence of edgeless cities (Lang, 2003) as well as the need to look further into the region, rather than only into the metropolitan area. Finally, there are alternative approaches to understanding urban structure that propose the existence of a fragmented and complex postmodern urban structure (Dear and Flusty, 1998).

Diverse studies with different methods have found multiple subcenters in various cities. Although such studies may suggest the existence of subcenters in these cities, their results cannot be generalized: first, because the methods have been applied on a case-by-case basis, such that criteria employed (such as number of jobs thresholds) may make sense in some places and not in others; and secondly, because of self-selection issues. For example, the most important subcenter identification techniques have been applied to cities such as

Los Angeles (Giuliano and Small, 1991), Chicago (McDonald and McMillen, 1990), San Francisco (Cervero, 1998), Houston (Miezkowski and Smith, 1991), Mexico City (Aguilar and Alvarado, 2005; Graizbord and Acuña, 2005; Suárez and Delgado, 2009) and Toluca, Mexico (Garrocho and Campos, 2007). Except for Toluca, the smallest of these cities in which subcenters have been identified had a population of over four million by 2005. Most cities in the world are much smaller and are bound to be less complex in terms of urban structure.

Of Mexico's fifty-six metropolitan areas, more than one-half have a population between one hundred thousand and half a million. One-third of the urban population lives in cities of 100 000 or less, and one-half of the population lives in cities of 750 000 or less (SEDESOL/CONAPO/INEGI, 2005). That is, most cities in Mexico are small. This also means that most cities probably have simple urban structures that are well represented by urban rings. In any case, whereas the subcenter-identification approaches seek secondary economic agglomerations within cities, our aim is to find out how population and employment characteristics cluster around city centers.

Previous studies based on the concentric city model have been used to explain the central location of low-income housing for rent (Bromley and Jones, 1996; Masey, 1996), the dynamics of population and employment (Delgado, 1988), periurban trends of 'mega cities' (Villa and Rodríguez, 1996) and the population's age composition across urban rings (Pick and Buttler, 1998), and to describe ecological areas within cities (Ward, 1998). Rings have also been used to explore urban expansion around main urban centers (Suárez and Delgado, 2007), zonal structure (Abbott, 1974), income segregation and commuting (Mohan, 1994) and mixed-income housing in the urban-rural periphery (Banzo, 1998). The classification of rings in these studies has, for the most part, been based on bid-rent theory (Alonso, 1964), and thus it has two common characteristics that depend on distance to the city center: job density and population density.

The urban rings approach was first employed in Mexico by Dotson and Dotson (1954) to com-

pare Merida and Mexico City. They searched for cultural differences between residential areas, as described by the Burgess (1923) model. Unikel *et al.* (1974) described rings in Mexico City based on population and urban contiguity. Their scheme was then replicated by Negrete and Salazar (1986) for 67 cities in the country. Garza (1988) defined rings by taking a geometric approach and Delgado (1988) changed the approach and defined rings in Mexico City on the basis of historical conurbation stages. Recently, Sobrino and Ibarra (2005) used a principal components analysis to identify city centers and first ring municipalities in 40 metropolitan areas of the country. Delgado (1998) also made a descriptive attempt at identifying city sectors in Mexico City.

All these studies have used municipalities as the unit of aggregation. This represents a problem for small metropolitan areas that are composed of only two or three municipalities.

STUDY AREA

Our study area is composed of eight metropolitan areas that surround Mexico City, forming its Regional Belt (MCRB). These metropolitan areas were delimited by Sobrino and Ibarra (2005) and are as follows: Toluca to the west; Cuernavaca and Cuautla to the south; Puebla, Tlaxcala and Apizaco to the east; and Pachuca and Tulancingo to the north (Figure 1).

The population of the region (Mexico City with its Regional Belt) reached 28.3 million in 2005. Close to 93% of this population was urban. Almost 70% of the population in the region was concentrated in Mexico City; however, between 2000 and 2005, 35% of the region's urban population growth occurred in the rest of the metropolitan areas. According to forecasts (SEDESOL/CONAPO/INEGI, 2005), by 2020 one-third of the region's urban population growth will occur in these other cities. While Mexico City will grow by 11%, the smaller metropolitan areas such as Tulancingo and Apizaco will have population increases of up to 45%. Between 1990 and 2000, the rate of population growth in the region was 21.7%. Except for
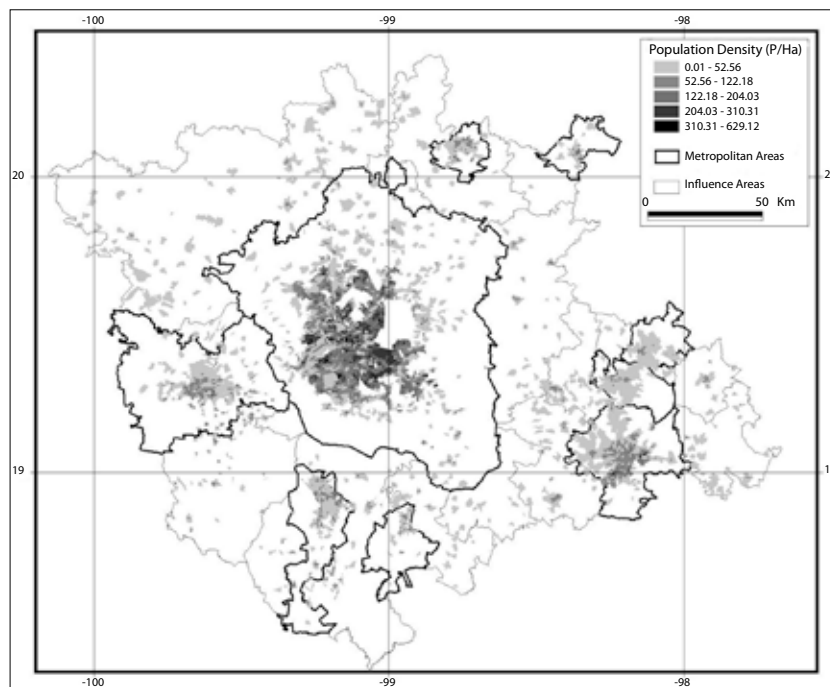

Figure 1. Urban area and population density in the Mexico City Regional Belt, 2005. *Source*: Authors' calculations with data from INEGI (2005).

Mexico City, all the cities in the region surpassed that rate. The same is true of the period 2000-2005 for all the cities except Cuautla[2] (Table 1).

Economic activity shifted between 1990 and 2004 from an industry-based to a service-based economy. Whereas 43% of economic activity was in the secondary sector in 1989, by 2004 that sector represented only one-quarter of regional jobs. The services sector has followed the opposite trend. This is especially true of Toluca and Tlaxcala, in which more than 50% of jobs were in the secondary sector in 1989 (Table 2). Whereas overall job growth in the secondary sector was 34% between 1989 and 2004, in the commercial sector it doubled, and the service sector grew by 255% in the same period.

Overall, population growth has been slowing down in Mexico City while it has increased in other metropolitan areas in the region. The same pattern is true of economic activity. Even though in absolute terms the highest growth still occurs in Mexico City, most of the other metropolitan areas are growing faster relative to their size. The question is what the resulting urban structure is in each case. Are there distinct forms of urban growth with distinct urban structures in different metropolitan areas? Is there a regional pattern? Can stages of metropolitan evolution be identified? By exploring the extent of the formation of urban rings and city sectors and their characteristics, we might be able to begin answering these questions.

METHODS

We propose to research the spatial arrangement of urban clusters using tracts as the minimum unit of aggregation. Since bid-rent theory (Alonso, 1964) has been used to explain the urban structure of cities including the shifts to polycentrism to regain spatial equilibrium (O'Sullivan, 1996) we base our model assumptions on distance, job and population density.

To identify urban clusters we follow three steps. First, we generate a combined urban density index

Table 1. Population of Metropolitan Areas in Mexico City's Regional Belt 1990-2005

Metropolitan area	Total population (millions)			% Change	
	1990	2000	2005	90-00	00-05
Mexico City	15.56	18.4	19.24	18.3	4.6
Tulancingo	0.11	0.15	0.16	36.4	6.7
Pachuca	0.2	0.29	0.34	45.0	17.2
Toluca	1.06	1.47	1.63	38.7	10.9
Cuautla	0.17	0.22	0.23	29.4	4.5
Cuernavaca	0.56	0.76	0.81	35.7	6.6
Puebla	1.41	1.83	2.05	29.8	12.0
Tlaxcala	0.21	0.27	0.3	28.6	11.1
Apizaco	0.1	0.14	0.16	40.0	14.3
Peripheries	2.64	3.29	3.44	24.6	4.6
Total	22.03	26.81	28.37	21.7	5.8

Source: INEGI 1990, 2000 and 2005.

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[2] It is possible that most of the growth of Cuautla is happening in the municipality of Yautepec which is not yet officially part of the Cuautla MA.

Table 2. One-digit Economic Sector Employment Shares in Metropolitan Areas of the MCRB, 1989-2004

Metropolitan area	% of Total M.A. jobs 1989			Total 1989	% of Total M.A. jobs 2004			Total 2004
	Sec.	Comm.	Serv.		Sec.	Comm.	Serv.	
Mexico City	41.6	30.8	27.7	1,967,793	24.5	28.4	47.1	4,017,211
Tulancingo	32.6	41.4	26.0	10,482	25.6	40.1	34.3	24,270
Pachuca	31.5	42.0	26.5	18,628	30.3	33.7	36.0	62,958
Toluca	55.3	28.9	15.8	88,520	36.4	33.6	30.1	251,444
Cuautla	18.4	48.1	33.4	12,029	18.5	43.6	37.9	32,919
Cuernavaca	40.0	32.4	27.6	58,748	24.8	33.8	41.4	144,396
Puebla	47.6	29.0	23.4	166,173	34.8	31.6	33.6	373,812
Tlaxcala	54.0	27.5	18.5	15,653	37.6	33.1	29.3	40,222
Apizaco	49.0	32.7	18.3	9,870	41.8	31.6	26.6	29,730
Peripheries	53.7	29.7	16.6	128,834	37.3	35.1	27.6	349,089
Total	42.9	30.8	26.3	2,476,730	26.8	29.7	43.4	5,326,051

Source: Authors' calculations with data from INEGI 1989 and 2004.

(CUDI) through a principal components analysis. Second, we run a local spatial-autocorrelation analysis on the CUDI to see whether urban rings form. Third, we assign values to each of the cluster categories and run descriptive statistics to validate the results.

Data used for the urban ring analysis correspond to the 2005 population count and the 2004 economic census at the tract (AGEB[3]) level. We additionally ran population figures and descriptives using the 1990 and 2000 population census and the 1989 and 1999 economic census data in order to compare changes between periods. Our working delimitation of metropolitan areas corresponds to Sobrino's (2005) delimitation.

Combined Urban Density Index (CUDI)
To generate the CUDI we used a principal components analysis to extract the common variance of variables that are associated with distance to the city center. To capture a non-linear gradient, we used natural logarithms. The analysis was run

for all the cities at once; however, variables were standardized relative to each city. This ensured comparable results for all the cities regardless of their difference in size.

Variables in the analysis and expected results
Population density (Ln). We expected a negative correlation with distance to the city center.

Population density squared (Ln). We expected a negative correlation with distance to the city center. If any of the cities are undergoing transition to a quadratic population gradient, a second component with positive population density coefficient and negative population density squared coefficient could appear with significant eigenvalues.

Employment density (Ln). We expected a negative correlation with distance and a steeper density gradient when compared to population density. If there is evidence of sub-centering, a second component could appear with a different structural weight or coefficient direction.

Distance (Ln) to city center (normalized). Distance was normalized such that each tract that represented a city center had a value of 0, and each tract furthest from the city center had a value of

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[3] AGEBs (Área Geográfica Estadística Básica) are the smallest statistical level of aggregation used by the Mexican census office.

1, to ensure comparability within cities. Distance was expected to be negatively correlated with the rest of the variables in the factor with the largest proportion of explained variation.

Local spatial-autocorrelation algorithm

Using our CUDI, we ran a local spatial autocorrelation procedure using the local Moran's I statistic (Anselin, 1995). Local Moran's I is defined as:

$$I_i = \frac{(x_i - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2/n} \sum_{j=1}^{n} w_{ij}(x_j - \bar{x})$$

where I_i is the local Moran's I coefficient, X is the value of the variable of interest, w_{ij} is the matrix of spatial weights, and n is the number of observations. Through calculating z-values of the local Moran statistic (see Anselin, 1995; Getis and Ord, 1996) it is then possible to identify two types of spatial clusters, two types of outliers and a no-clustering category (Table 3):

The analysis was carried out in two iterations for each city as a separate unit. We expected to find HH clustering in city centers. and LL clustering in peripheral areas, and for intermediate areas to show up as NC's (mean overall values among mean variance). To ensure that the NC category was not absent from the clustering because of the effect of the values in the city center. on the metropolitan averages, we ran the autocorrelation algorithm a second time. Whereas the first iteration included all the tracts in the cities' metropolitan areas, in the second iteration we omitted tracts that had shown up as HH clusters. Additionally, we expected to find HL outliers in intermediate and peripheral areas that could indicate some degree of subcentering for the largest cities if they showed high employment densities.

Urban ring classification criteria

Once the analysis had been run, we used the following criteria to classify clusters.

a) HH clusters in the center were considered to be the city center. If an additional HH cluster appeared elsewhere, it would be treated as a sub-center as long as it showed a higher employment density than the mean for the metropolitan area; however, this last pattern did not occur in any of the cities.

b) LL clusters appeared towards the edges of cities. They were considered to be the metropolitan periphery when they were composed of tracts physically separated from contiguous urban area, but to be the edge ring when they were part of the contiguous urban area.

c) NCs were considered as a ring depending on their size, aggregate contiguity, form and location relative to the city center. In most cities, NCs appeared as the first ring (in most cases, the first ring represented the only ring besides the city center and the metropolitan periphery).

d) HL and LH values were for the most part ignored. LH clusters appeared mostly within the edge of cities surrounded by NCs or next to city centers. In the latter case they could be considered as low-density pockets within the city. They were considered to be part of the ring with which they shared the largest boundary. HL clusters appeared isolated, with no specific form, mostly within NCs. They were also considered to be part of the ring with which they shared the largest boundary, although their existence was noted, as they may be considered as candidate sub-centers in further research, although with a method appropriate for such endeavor.

Once clusters were classified, we generated maps for each city and calculated population and

Table 3. Cluster Types using Local Moran's I

Acr.	Values	Interpretation
HH	High-high	High values around neighbors with high values (cluster)
HL	High-low	High values around neighbors with low values (outlier)
LH	Low-high	Low values around neighbors with high values (outlier)
LL	Low-low	Low values around neighbors with low values (cluster)
NC	No clustering	Neighboring values are random (no cluster)

employment density for each ring, changes in these densities between 1990 and 2000 and general socioeconomic statistics. The results reveal what we believe to be intuitive urban concentric structures of early and medium-stage monocentric cities.

RESULTS

Combined Urban Density Index

Table 4 shows the component matrix of the factor analysis. Only one factor with an eigenvalue greater than 1 was extracted. This suggests that city structures in the region are not very complex, at least in the way these variables correlate. As would be expected, employment and population densities decrease with distance from city centers.

Urban ring structures

Figures 2 to 5 show our classification results, while Figure 6 shows employment and population densities per ring for each metropolitan area. The two southern cities, Cuernavaca and Cuautla (Figure 2), the two northern cities, Pachuca and Tulancingo (Figure 3), and Toluca (Figure 4), all had a similar ring structure: a city center, one urban ring and a metropolitan periphery. It is clear, however, that Toluca, the largest, is at a more advanced stage than the rest. In fact, Garrocho and Campos (2007), classified Toluca as a polycentric city, and found a set of industrial and commercial

Table 4. Combined Urban Density Index (CUDI) Component Correlation Matrix

Variable[1]	Component 1[2]
LN Population density	0.95
LN Population density squared	0.88
LN Employment density	0.66
Normalized distance	-0.59

[1] Variables standardized relative to each metropolitan area.

[2] 61% of variance explained

Source: Authors' calculations with data from INEGI (2004; 2005).

subcenters that could be represented as HL clusters according to our method. Although its periphery is non-contiguous, there is a clear ring of segmented urban areas around it that may consolidate as its second urban ring in the near future. Although the northern and southern segments of this peripheral ring fall into municipalities that are not considered to be part of its metropolitan area, we have included them as such because they qualitatively share form and distance with the rest of the non-contiguous urban areas in this ring. It is worth noting that in between the small urban areas of this periphery there are hundreds of localities with populations of 2500 or less. These do not appear as urban areas in the official statistical urban area, but would be impossible to ignore *in-situ*.

Puebla, Tlaxcala and Apizaco (PTA) (Figure 5) are three centers of what appears to be one consolidated metropolitan area (CMA). Puebla is the dominant city of the PTA urban system and is evidently the most complex. It is the only city in our study area that has more than one urban ring. Hierarchically, the second city in the system appears to be Apizaco, which has only one edge ring, as does Tlaxcala. Apizaco has a slightly higher population density in its city center than does Tlaxcala, although Tlaxcala has a larger population, and both have similar job densities (Figure 6). However, as shown in Table 1, Apizaco has been growing faster that Tlaxcala.

According to Sobrino and Ibarra (2005) and CONAPO (2005) Puebla and Tlaxcala are considered to be the same metropolitan area. Apizaco, however, has not been taken into account. This is because neither of the metro-area identification techniques contemplates the possibility of the existence of a secondary city center. Since their methods consist partly of measuring work trips to the city center, it is likely that Apizaco does not appear as part of that CMA because it is linked to a greater degree with Tlaxcala than with Puebla because of the relative distances. Even so, it is quite clear that urban contiguity should be a sufficient criterion to include a city as a part of a larger urban area. What is important is that if taken separately, these would be the ring structures of two early-stage (Tlaxcala and Apizaco) and one medium-stage (Puebla)

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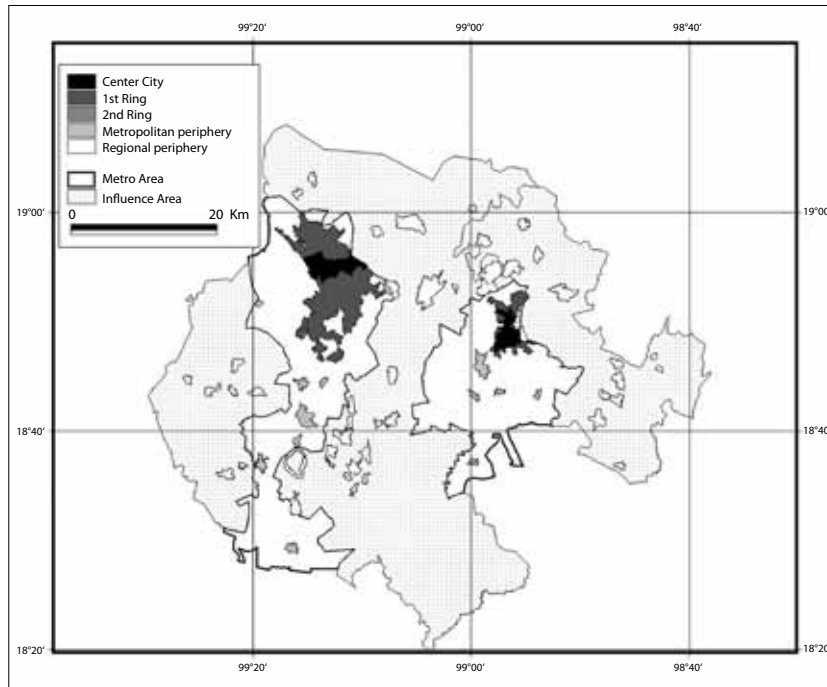

Figure 2. Urban rings in Cuernavaca and Cuautla metropolitan Areas, Mexico. *Source*: Authors' calculations with data from INEGI (2004; 2005).
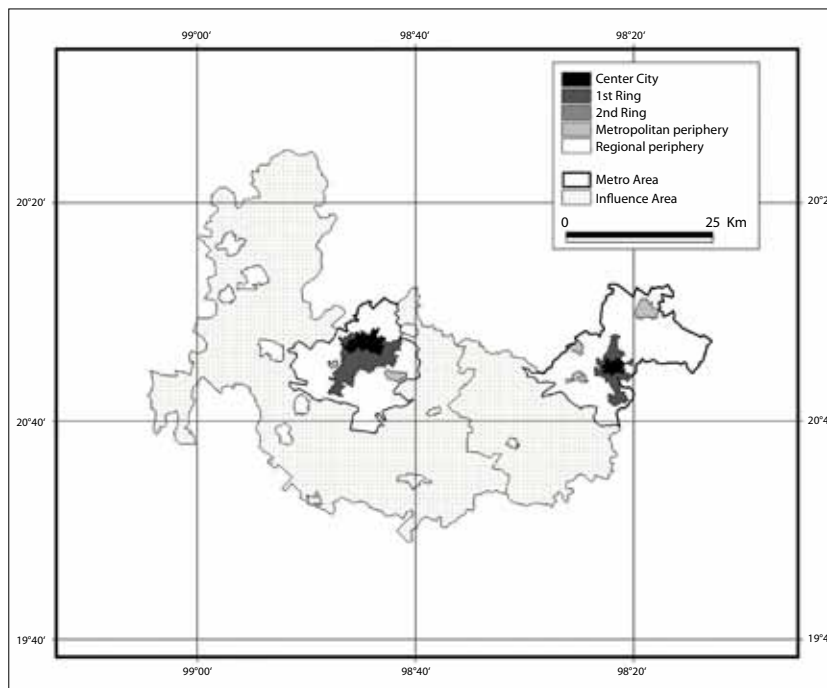

Figure 3. Urban rings of Pachuca and Tulancingo Metropolitan Areas, Mexico. *Source*: Authors' calculations with data from INEGI (2004; 2005).
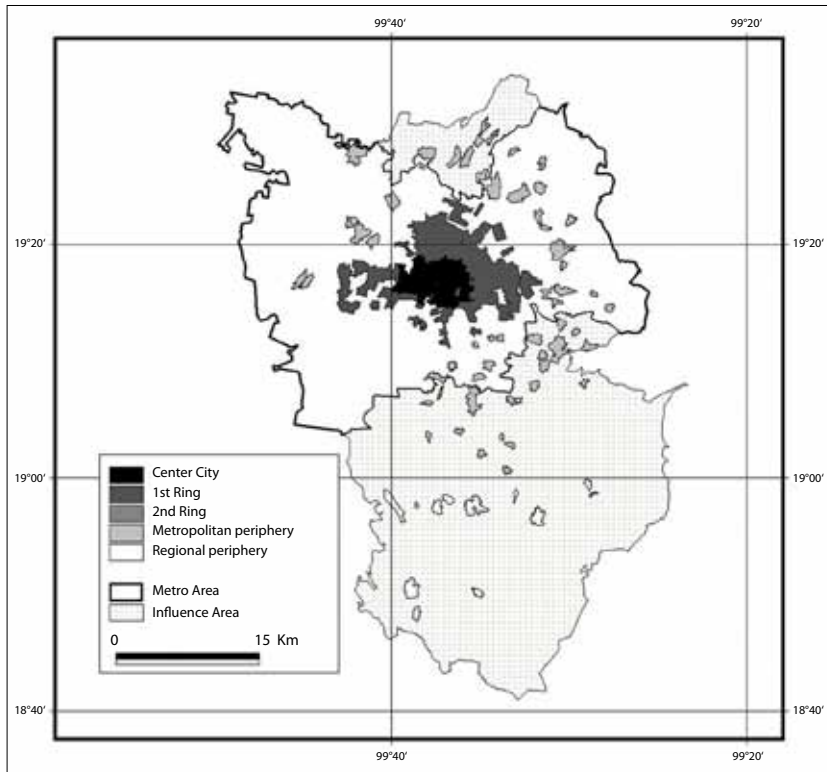
Figure 4. Urban rings of the Toluca Metropolitan Area, Mexico. *Source*: Authors' calculations with data from INEGI (2004; 2005).
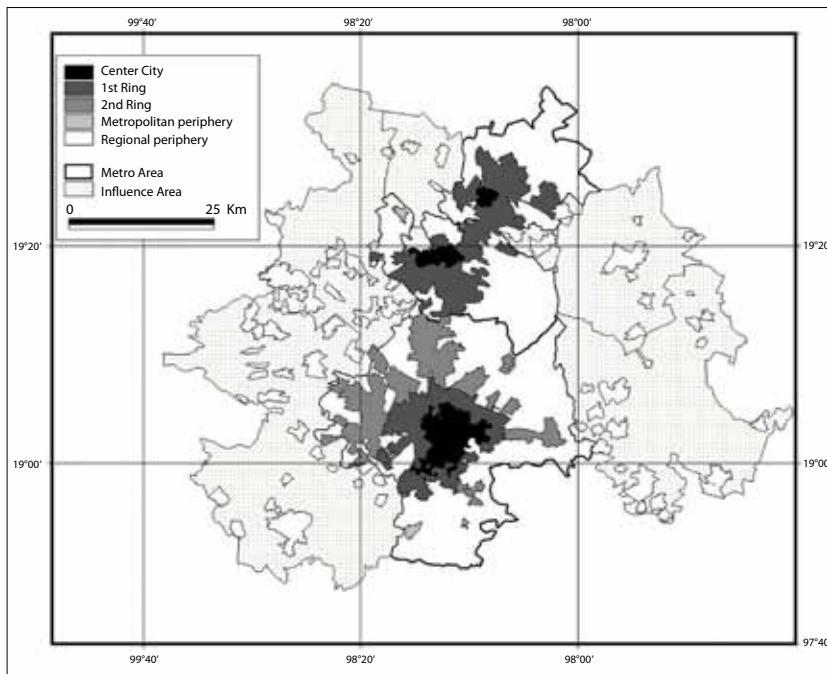

Figure 5. Urban rings of Puebla, Tlaxcala and Apizaco Metropolitan Areas, Mexico. *Source*: Authors' calculations with data from INEGI (2004; 2005).

monocentric cities. Together, however, these three cities form a more complex tricentric city.
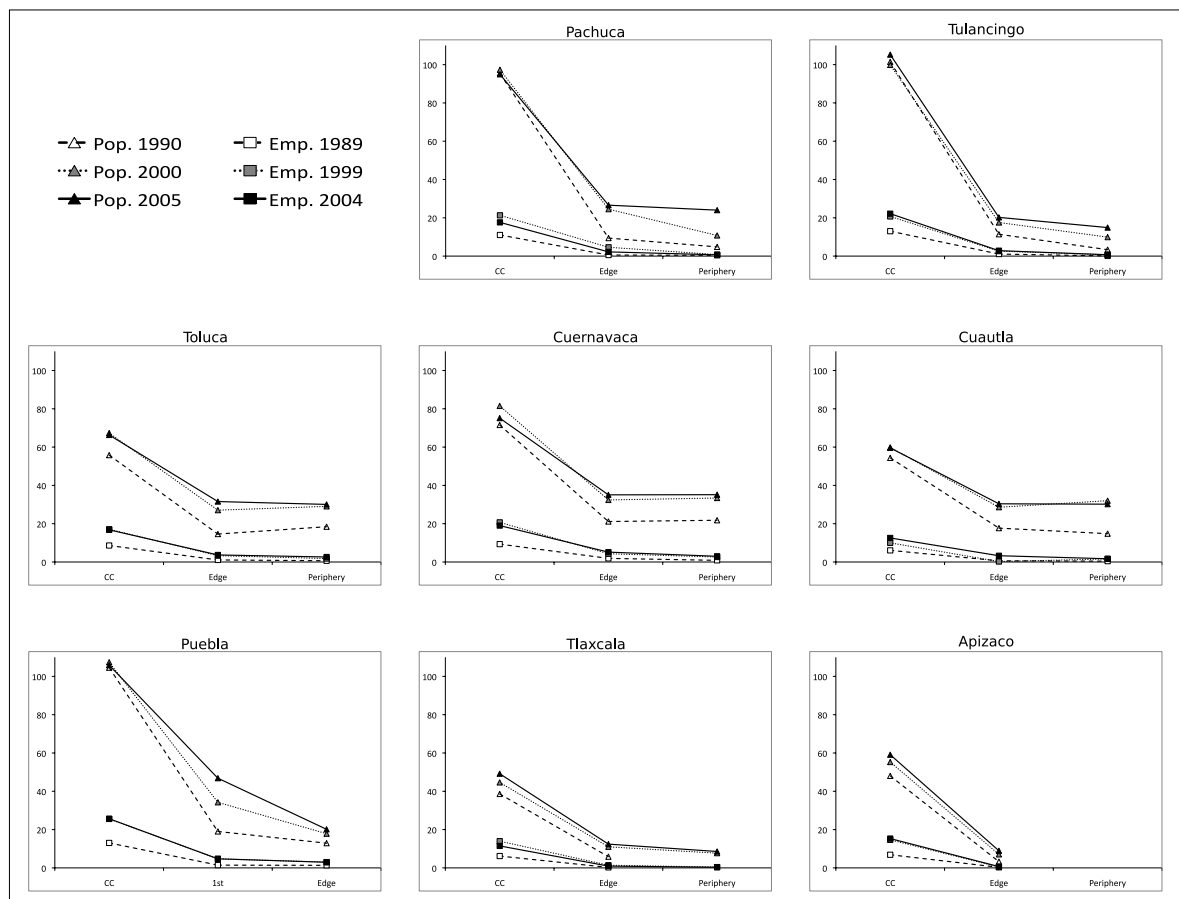
Characteristics of urban rings

From the graphs in Figure 6 it is not surprising that the clusters produced by the local autocorrelation procedure form such neat rings around city centers. Although population densities are definitely urban densities in city centers, they fall dramatically towards the edge rings. Three of the non-contiguous metropolitan peripheries in the Cuernavaca, Cuautla and Toluca metropolitan areas had higher densities than their edge rings in 2000 but equaled the latter by 2004. This is probably the result of slower updates in the official delimitations of the urban tracts due to slower than expected

population growth or the product of a process of self-containment in small peri-urban areas.

In the case of the Puebla-Tlaxcala-Apizaco urban system, Tlaxcala's edge ring has a lower density than that of Puebla. This suggests that Tlaxcala's ring could actually be Puebla's third urban ring, or, judging from the densities, its periphery. In the same sense, Apizaco's edge ring has a lower density than Tlaxcala's edge ring, although this may be the result of the delimitation of the area of tracts in the peripheries and not of actual net densities. We suggest that it is possible to classify the PTA metropolitan area as a hierarchical tricentered city structure.

Between 1990 and 2000 all city centers saw

Source: Authors' calculations with data from INEGI 1989, 1990, 1999, 2000, 2004 and 2005.

Figure 6: Population and Employment Density Changes by Urban Ring in Eight Metropolitan Areas.

employment and population density increases. Between 2000 and 2005, however, most city centers seem to have maintained previous densities while edge rings and peripheries had most of the growth dynamics. This pattern should be checked by analysis of data from the 2009 economic census and 2010 population census.

Regarding specialization, Table 5 shows economic specialization per urban ring with location quotients (LQs) higher than 1.2; that is, where the proportion of jobs in the ring surpasses the regional proportion by at least 20%. One must take into account that the denominator of the LQs includes Mexico City, and thus jobs in high-end services that are overwhelmingly located in Mexico City do not show up as significant in any of the seven metropolitan areas under study.

All city centers except Pachuca, which is highly specialized in mining, have their highest location quotient in the services sectors. All city centers except Tlaxcala have significant specialization in education and health, which may be indicative of a government-run formal economy. Specialization in manufacturing occurs mostly in edge rings. It is worth noting that Puebla's and Tlaxcala's edge rings, which are contiguous, have the highest location quotients in that sector. Finally, metropolitan peripheries are mostly characterized by commercial activity, although some manufacturing specialization does occur.

CONCLUSIONS

Regional urban structure

Several characteristics of the MCRB metropolitan areas are worth noting. First, the economic base of these cities is at a very early stage. Most city centers specialize in government-run economic sectors (education and health), which also reflect the dominant role of Mexico City in the region's economy. Other important sectors are manufacturing and commercial activity in edge rings and metropolitan peripheries.

Second, except for Puebla, all metropolitan areas are in an early structural stage. Perhaps Toluca, the second-largest city of the eight studied,

will consolidate its peripheral ring of scattered urban areas into a second ring in the near future; however, as of 2005 it remained a metropolitan area with one contiguous urban ring. Puebla, on the other hand, the largest city in the system (and the fourth-largest in the country), is the only city with two rings. Puebla is also the dominant city of what we believe to be a consolidated metropolitan area with three city centers.

Further research should look at the evolution of the Puebla-Tlaxcala-Apizaco Metropolitan Area. Research should ask whether its transition from a monocentric to a polycentric form has been driven by an urban efficiency process or if it is the result of growth and consolidation, and if the growth of Tlaxcala and Apizaco may be attributed to a metropolitan process. If the latter is true, it could mean that in some cases, subcenters emerge not because of the need for urban efficiency in a growing city but because they were already there. Again, this idea is a subject for further research.

Limitations of the analysis

We have proposed a method by which urban rings can be identified at the tract level. The need for this method stems from the fact that the municipalities of most cities in Mexico are too large to be used to identify city structures, and because urban rings are a useful spatial aggregation by which to compare dynamics within and between cities and to organize city data for presentation in tables and maps.

The main problem with urban ring delimitation is that there is no straightforward definition of what a ring should be or what it should contain. On the basis of bid-rent theory (Alonso, 1964), we use the spatial-autocorrelation of the combined urban density index to find spatial cut-points for rings.

Although we cannot be sure that our cut-points are always precise, statistically they make sense regarding population and employment densities, as well as economic specialization. We believe that this technique would be greatly enhanced with dwelling age statistics; however, these are currently not available at the tract level in Mexico.

Table 5. Economic Specialization (Location Quotients) by Ring Relative to the MCRB (2004)

Metro-area	Ring	Mining	Manuf.	Com.	Educ.	Health	Rec. & Cult.	Rest. & Hotels
Tulancingo	City center			1.4	2.1	2.0		
	Edge ring	1.6	1.5	1.4				
	Periphery	16.1		1.7				
Pachuca	City center	4.9		1.3	1.5	2.1		1.3
	Edge ring			1.4	1.9		2.3	1.2
	Periphery			1.7				2.9
Toluca	City center				1.2	1.2		
	Edge ring		1.5	1.3				
	Periphery	1.5	1.4	1.4			1.7	
Cuautla	City center			1.4	1.5	2.1	1.8	1.6
	Edge ring			1.9				1.4
	Periphery	2.1		1.8		1.5	3.0	1.6
Cuernavaca	City center			1.2	1.7	2.3		1.7
	Edge ring	1.4			1.5		1.9	1.8
	Periphery			1.6			2.9	1.6
Puebla	City center				1.9	1.5		
	1st ring		1.7		1.9			
	Edge ring		2.4					
Tlaxcala	City center		1.3				1.4	
	Edge ring		2.4					
	Periphery			2.3				
Apizaco	City center			1.5	1.6	1.5		1.4
	Edge ring		1.7					

[a] For simplicity, only LQs higher than 1.2 are shown. Any subsector not shown is the product of the absence of any ring having an LQ higher than the 1.2 threshold.

Source: Author's calculations with data from INEGI (2004).

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