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Urban sprawl and the growing geographic scale of segregation in Mexico, 1990–2010

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ABSTRACT

Urbanization is linked to economic growth, and agglomeration economies mean that people in larger cities are more productive. However, urban expansion is also associated with congestion, localized environmental damage, and potentially, social segregation. In this paper we examine how urban expansion and changing urban spatial structure affects the level and scale of socioeconomic segregation of cities in Mexico. We measure different dimensions of urban spatial structure, and segregation by income and education at different geographic scales in 100 Mexican cities from 1990 to 2010. We then examine correlations between the two sets of variables, and run multivariate regressions to assess how changes in urban spatial structure relate to changes in the level and scale of segregation. Findings reveal that as cities expand, inhabitants experience greater levels of socioeconomic segregation, especially at a larger geographic scale. However, an increasing centralization of cities is associated with less segregation. This process works differently for segregation by education and income. For the former, less educated households are become more segregated in expanding, centralizing cities. For the latter, it is high-income households who are becoming more isolated. This study reveals provocative generalizations about the association between urban expansion and increasing segregation in Mexico. It suggests that movements into and out of central cities, rather than urban fragmentation or sprawl, shape how household mobility reorganizes social space.

1. Introduction

Urban growth is a positively linked to economic development, with some caveats (Ahrend, Farchy, Kaplanis, & Lembcke, 2014; Puga, 2010). When accompanied by commensurate gains in employment, it generates increasing returns to individuals' economic activity and leads to higher productivity. Yet, urban expansion and increased economic activity can also create congestion costs and localized environmental damage. The magnitude of these costs, and the degree to which they mitigate the benefits of urban growth, depends on a number of factors. Key among them is the spatial structure of the urban area. Urban expansion is often connected to unequal socio-economic spatial structures, especially in Latin America (Bosdorf, Hildalgo, & Vidal-Koppmann, 2016) and other rapidly urbanizing regions of the globe (Winarso, Hudalah, & Firman, 2015). The growth of new, homogenously low-income neighborhoods is thought to perpetuate rifts in societies and exacerbate inequalities through unequal service provision and disparities in environmental conditions.

The potential for social stratification of space that accompanies urban growth is especially relevant in the Mexican context. The rise of a new form and scale of housing production in Mexico led to new urban spatial structures that exacerbate social divisions (Alegría, 2008; OECD, 2015). The reform and dramatic expansion of Mexico's housing finance system began in the early 1990s fueled the construction of large-scale suburban housing development and congruent expansion of Mexican cities (Monkkonen, 2011a). Prior research has connected housing finance to increasing segregation during the 1990s (Monkkonen 2012a), but this work did not address the ways in which urban growth and the changing spatial structure of cities inevitably shapes the distribution of people within them. The boom in gated communities for the working-class in Mexico (Garcia Peralta and Hoffer 2006) and the housing filtering new developments enable (Ward, 2009, pp. 114–134) illustrate the type of changes that, we hypothesize, shifts the social mix of urban neighborhoods towards greater social separations at larger geographic scales.

This study, therefore, examines whether and how patterns of socioeconomic segregation in Mexico are related to urban expansion and urban spatial structure. To examine this relationship, we address three

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questions. Do cities that grow more rapidly experience a larger increase in segregation by income or education? Does a more sprawling form of urban growth also lead to more spatial separation between social groups? Is the geographic scale of segregation affected by changes in urban structure?

The analysis combines cutting-edge measures of urban spatial structure and segregation. We utilize spatial indexes of segregation (Reardon & O'Sullivan, 2004) to measure and compare segregation levels at multiple neighborhoods scales. They are also ordinal and decomposable across levels of income and education (Reardon, 2009; Reardon & Bischoff, 2011). This allows us to compare changes in, for example, segregation of high-income and low-income households separately. We use small area census data from 1990, 2000 and 2010 for the 100 largest cities in Mexico.[1] After we calculate indexes in these three time periods, we model their changes and changes in the spatial scale of segregation as a function of urban growth and urban spatial structure.

We find that in Mexico, urban expansion (of land area, not population) is significantly associated with increases in segregation by education and income. Somewhat unexpectedly, we show that this change was driven by increases in the isolation of high-income households, rather than low-income households. Additionally, we find that cities that sprawled less experienced greater increases in segregation by education and income, a trend also driven by the isolation of high-income households. Additionally, increasing centralization is associated with an increasing geographic scale of segregation. That is, larger neighborhoods were more homogeneous in more centralized cities.

The findings about urban expansion and segregation are expected, yet the association between centralization and segregation runs counter to our model. The model predicts the boom in large, peri-urban housing developments for working class households – associated with less centralization –to lead to larger scale of segregation among low-income households. Yet it did not. These findings prompt us to question assumptions about the effects of urban growth, and prompt further study of urbanization patterns in countries like Mexico.

The paper is organized as follows. A brief literature review precedes an in-depth discussion of the measures of segregation and urban spatial structure and their changes from 1990 to 2010. Then, we report on and discuss the results of regressions analysis of the relationships between the two. The conclusion summarizes the findings, outlines directions for future research and reflects on policy implications.

2. Segregation and urbanization in Mexico

The relationship between urban expansion, urban spatial structure and social segregation, though highly context dependent, are relevant to all cities. Research in the United States, for example, has shown a significant, but non-linear, association between segregation and certain kinds of urban spatial structure, such as sprawl (Galster & Cutsinger, 2007). This work has mostly focused on racial segregation, however, because of its importance and clearer connection to United States suburbanization trends (Mieszkowski & Mills, 1993). The basic insights, such as the positive relationship between city size and socioeconomic segregation (Mills & Hamilton, 1994), generate important questions for the Mexican context and motivate this study, in part so that scholars from other countries learn from the Mexican experience.

The study of socioeconomic segregation has a long history in Mexico. Initially based on qualitative research, the use quantitative methods have gained importance in recent decades, in part due to the greater access to quality georeferenced data (INEGI, 2000; 2010) These data allow the use of techniques such as dissimilarity and entropy indexes that are more readily and consistently comparable. Existing comparative scholarship on segregation, notably the edited book by Roberts and Wilson (2009) on segregation across the Americas, make evident the need for consistent measures that are comparable across boundaries. The book's collection of case studies provides insightful conclusions about different cities and questions related to segregation, but leaves the reader without a consistent comparison between places.

Case studies of segregation in the large cities of Mexico such as Mexico City (Delgado, 1990), Tijuana (Alegría, 1994; Hernández Gómez 2001), and Monterrey (Garza 1999; González Arrellano and Villeneuve 2007) have led to a growing body of evidence on the topic, as well as some comparisons of these large metros (Ariza & Solís, 2009; Duhau, 2003; Rubalcava & Schteingart, 2000). The analysis of segregation across the national urban system by Monkkonen (2012b) confirms many of the extant descriptions of Latin American cities (Borsdorf, 2003; Ford, 1996; Sobrino, 1996); larger cities are more segregated, and poor neighborhoods tend to be more segregated than affluent ones.

Scholars in Latin America posit that new forms of urban growth and real estate development patterns exacerbate social inequality and segregation (Michelini and Pinto, 2016), as well as the geographic scale of these phenomena (Sabatini, 2006; Sabatini, Cáceres, & Cerda, 2001, pp. 25–28). Mexico is no exception. Ward (2009, pp. 114–134) examines the relationship between de facto land use and corresponding valuation and segregation and found significant heterogeneity. He argued that the process by which land is socially produced serves to differentiate neighborhoods and the levels of heterogeneity within them. In particular, the higher barriers to entry higher-income areas impose on development facilitates the creation of homogenous upper- and middle-income enclaves. At the same time, the informality of much of the market enables substantial mixing to take place through processes of filtering such that, with the exception of very poor areas, most neighborhoods have relatively high levels of social mix.

Monkkonen (2012a) tested the relationship between new forms of housing finance and segregation across the country's 100 largest cities, and found that in cities where more new housing was built under the public finance system, segregation increased by a greater amount. The basic conceptual model of that study is that the new form of housing development – speculative building of identical houses in large tracts – will create neighborhoods more homogenous than those built in the traditional, incremental manner, in which households expand and improve their homes as their incomes and families grow. However, that study did not examine the spatial aspect of this process explicitly, which is a central mechanism given the size of the housing developments being built.

3. Measuring urban growth, urban form and socioeconomic segregation

Measuring the spatial structure and social-spatial structure of cities is a complex endeavor. For the former, we chose a handful of measures that best fit the Mexican context and are most widely used in the academic literature. Essentially these measures attempt to capture the density and shape of cities, and the distribution of that density within the urban area (Anas, Arnott, & Small, 1998).

Thus, we use the most basic measures of urban growth (population and land area), a simple gross population density, and measures of three aspects of urban spatial structure: centrality, proximity, and discontiguity. These measures are calculated exclusively based on census tract (AGEBs in Mexico) populations. The Mexican census bureau, INEGI (Instituto Nacional de Estadística y Geografía) distinguishes between urban and rural census tracts, meaning that urban census tracts end at the edge of urbanized areas and create a boundary for them. For a longer discussion on measuring urban structure in Mexico, see Montejano, Monkkonen, Guerra, and Caudillo (2017).

We use the centrality index proposed by Galster et al. (2001), which measures the degree to which people or jobs are located near the city center. It is a sum of the inverse distance of each census tract from the

[1] The maps for 1990 are not available from the Mexican census bureau, but we have created them in a previous study (Monkkonen & Comandon, 2016).

city center, weighted by thei population. This 'average distance' is divided by the square root of the total urban area in order to standardize it by city size.

We use a proximity index, developed by Angel, Parent, and Civco (2010a), to assess urban compactness. It measures the circularity of an urbanized area, and takes the value of one when the city is a circle, and zero under perfect linearity. We improve on the measure as presented by Angel and colleagues by incorporating the issue of non-developable land, such as bodies of water or steep hills. The proximity index is effective in its simplicity, but does not account for the distribution of people or activities within the city.

We also use Amindarbari and Sevtsuk's (2015) discontinuity measure as it is the most straightforward measure of fragmentation we find. Galster et al. (2001) propose a continuity measure, the inverse of which would be discontinuity or the extent to which urban areas develops in a leapfrog pattern. However, it is quite complex to implement. Other fragmentation measures depend on satellite imagery data is preferable in some ways but requires extensive processing.

Mexican cities have continued to grow rapidly in the end of the 20th and beginning of the 21st century. A report by the Secretary of Social Development (SEDESOL) in (2011) presents dramatic statistics and maps of the expansion of urban areas from 1980 to 2010, showing how some cities added urban space many times their size in 1980 during this time period. Yet it is important to assess more than just a city's degree of urban growth to understand how expansion affects social-spatial structure. Raw numbers can hide important variations.

Most large cities in Mexico lost population in their central zones during the 1990s and 2000s as they simultaneously built new, high-density housing developments in the periphery (Monkkonen & Comandon, 2016). Thus, examining changes in overall density can overlook important differences between cities' internal organization.

Table 1 presents percentage changes in the different measures of urban growth and urban spatial structure, for the two time periods under study (1990–2000 and 1990–2010) to match the available change data for the segregation measures.

Clearly, the changes during a twenty-year period will be larger than those in a ten-year period, so their comparison does not yield much information. We see that cities' population grew by a much greater degree than their land areas did, and thus urban population densities also increased. This refutes the argument made by the abovementioned report by SEDESOL (2011). This report incorrectly presented population data by municipality to calculate the population density of urban areas that generally occupy a small portion of municipal land. This dramatically overestimates decreases in population density in most cities because rural populations have been moving to cities at a rapid rate. A longer description of this discrepancy can be found in Monkkonen and Comandon (2016).

The other big change is in cities' relative centrality, which increased by more than half. The combination of rapid horizontal expansion, with increasing density and centralization, reflects the complex nature of urban growth in Mexico, and how it contrasts with changes in much of the world (Angel, Parent, and Civco, 2010b). Using the term sprawl to describe these changes is perhaps not appropriate, in spite of the homogenous appearance of single family tract homes being built, because of the high density of the new peri-urban housing developments (Monkkonen 2011b).

Table 1
Changes in urban spatial structure, 1990–2000, 1990–2010.
Source: Authors with INEGI, 1990, 2000, and 2010.

Variable	Change 1990–2000			Change 1990–2010		
	Mean	Median	Std. Dev	Mean	Median	Std. Dev
Population	0.35	0.29	0.50	0.66	0.57	0.64
Land Area	0.26	0.20	0.46	0.47	0.33	0.67
Density	0.08	0.07	0.16	0.16	0.12	0.22
Centrality	0.63	0.42	1.07	0.91	0.60	1.21
Discontiguity*	0.18	0.00	1.24	0.17	0.00	1.02
Proximity*	0.68	0.06	2.41	0.73	0.13	2.43

Notes: * Extreme outliers (above 10,000 percent change) were excluded, for Discontiguity this was seven observations and for Proximity two.

3.1. Measuring socioeconomic segregation in cities

Socioeconomic segregation is the relative residential location of different socioeconomic groups in cities. Relative, that is, to one another. The indexes we use measure the homogeneity of neighborhoods by income or education, and then compare this to the overall distribution of income or education in a city. The ordinal spatial entropy index – developed by Reardon and colleagues (Reardon & Bischoff, 2011; Reardon & O'Sullivan, 2004) – is based on the information or entropy index developed by Theil (1972). A brief description of the index we use is provided below. For more detail, see Monkkonen and Comandon (2016).

One of the chief advantages of the ordinal spatial entropy index is that it accounts for the ordinal nature of the income and education variables we use. Both variables contain information beyond households belonging to different income or educational levels, which other indexes do not capture. Other indexes simply measure the unevenness of households belonging to other groups without taking into account the social distance that exist between those groups. There is no possibility to operationalize social distance for variables like race and ethnicity, but we know that social distance between low-income and high-income households is greater than it is with middle-income households.

The ordinal measure, therefore, is based on the assumption that low-income households who have mostly high-income neighbors is qualitatively different from living in a predominantly middle-income neighborhood. This also means that the index can be easily disaggregated across the distribution of a variable (to calculate the segregation of high-income households separately from that of low-income households). Thus, we examine the segregation of high and low-income households separately. The index can also be used to graphically represent segregation continuously across the income (or education) distribution.

A second advantage is that the ordinal spatial entropy index is explicitly spatial. All measures of segregation are spatial. They assess the relative homogeneity of different neighborhoods. In general, however, the spatial nature of a measure is implicit. Measures are usually based on census tract or small area data with neighborhood boundaries determined by whatever data aggregation the national census bureau chooses. Some countries have larger neighborhood boundaries than others, some draw tracts based on population, whereas others draw tracts based on size (for an in-depth discussion, see Monkkonen & Zhang, 2014). To calculate the spatial-ordinal entropy index, we create neighborhoods of different sizes using AGEB data as a base, and aggregating AGEBs in circles of increasing radii; 200 m, 500 m, 1000 m, and 2000 m.

This creates a consistent geographic scale for the segregation indexes and allows us to compare segregation at different scales. Sabatini et al. (2001) have discussed the scale question as a common problem in measuring and comparing segregation in Latin America. We calculate a Macro/Micro Ratio, which is the segregation index at the 2000-m scale divided by that of the 500-m scale, in order to compare and assess the changing relationship between larger scale and small scale segregation trends in cities.

Table 2 reports the averages (means and medians) of segregation indexes for education in 1990 and 2010 and income in 1990 and 2000 across 100 cities in Mexico. We report values for the overall segregation along these two dimensions, the segregation of groups with high and low incomes and education levels, and the macro-micro ratio, which is the ratio of segregation for large neighborhoods (a radius of 2 km) to

Table 2
Measures of segregation by education and income.
Source: Authors with INEGI, 1990, 2000, and 2010.

Variable	1990		2000		2010	
	Mean	Median	Mean	Median	Mean	Median
Education (overall)	0.06	0.06	NA	NA	0.07	0.06
High-education	0.09	0.08	NA	NA	0.09	0.08
Low-education	0.03	0.03	NA	NA	0.05	0.05
Education Macro-Micro	0.17	0.12	NA	NA	0.19	0.17
Income (overall)	0.04	0.03	0.04	0.04	NA	NA
High-Income	0.06	0.05	0.07	0.07	NA	NA
Low-Income	0.02	0.02	0.02	0.02	NA	NA
Income Macro-Micro	0.11	0.12	0.17	0.14	NA	NA

Notes: NA indicates data not available.

that of small neighborhoods (tract sized). There are two gaps in the data used for this study; education data for 2000 and income data for 2010. INEGI changed the way it measured education in 2000 and because the categories do not match we do not calculate it for 2000. Unfortunately, INEGI did not report data on household income at the AGEB level for the 2010 census, thus we can only measure income segregation in 1990 and 2000.

We can see from Table 2 that the average values of segregation across the 100 cities either remained constant or increased slightly. The average geographic scale of segregation by education and income increased to a greater degree. Higher values of the macro/micro ratio indicate higher levels of segregation at a large scale relative to the small scale, such that larger scale patterns of segregation exert greater influence. The average (median) macro/micro ratio for education increased to 0.17 in 2010 from 0.12 in 1990, and that of income segregation went from 0.12 in 1990 to 0.14 in 2000, increases of 42 and 17 percent respectively.

Table 3 presents the averages of city-level changes in segregation. These give us a better sense of changes as they are averages of the 100 cities percent changes. For example, the means are all higher than medians, indicating that a few cities experienced disproportionately large increases. We see that the increases in segregation by income were fairly evenly distributed across the distribution of income, with the median city experiencing an increase in segregation of high- and low-income households of 25 and 29 percent. The changes are very different for education. The median city experienced a much larger increase in the segregation of low-education households, roughly 44 percent, whereas the segregation of high-education households only increased by eight percent.

4. Analysis of the relationship between urban growth, urban spatial structure, and segregation

We analyze the relationship between urban expansion and segregation in two steps. First, we estimate simple pairwise correlations between the percent change in the four different types of segregation outcomes described above, and the six measures of changes in urban spatial structure (including growth in population and land area). Then, we regress changes in segregation on these urban spatial structure variables, in order to test the associations while controlling for time-invariant characteristics of cities using fixed effects panel models.

Table 3
Changes in segregation by income and education.
Source: Authors with INEGI, 1990, 2000, and 2010.

Variable	Mean	Median	Std. Dev
Change in Income Macro–Micro Ratio (%)	43.3	13.7	201.5
Change in Low-Income Segregation (%)	33.1	29.2	52.6
Change in High-Income Segregation (%)	32.4	25.1	38.2
Change in Overall Income Segregation (%)	31.2	26.7	41.3
Change in Education Macro–Micro Ratio (%)	55.5	34.6	145.2
Change in Low-Education Segregation (%)	68.4	44.4	85.7
Change in High-Education Segregation (%)	8.9	7.3	34.0
Change in Overall Education Segregation (%)	14.2	8.0	29.7

Table 4 reports correlations between the percent change in segregation and percent changes in measures of urban expansion and urban spatial structure. Note that the changes in segregation by education are from 1990 to 2010 and changes in segregation by income are from 1990 to 2000.

Many of the correlations between changes in urban spatial structure and segregation are not consistent or strong. For example, changes in population or urban centrality are not correlated with any changes in segregation, and changes in the indexes of Discontiguity and Proximity (circularity) are only significantly associated with one or two segregation measures. Increasing population density is significantly negatively associated with segregation by education, with higher density cities being more mixed.

The most striking result is that urban expansion (as measured by land area growth) has the strongest and most significant correlation with increasing levels of segregation. The measure of urban population growth, itself strongly correlated to urban land growth,[2] is also positively associated with increasing segregation but not strongly enough to be statistically significant. Fig. 1 visualizes the difference between the two measures of urban growth, showing the scatter plot of correlation in changes in segregation by education and land growth on the left and population growth on the right.

The regression analysis reveals a more accurate picture of the relationships described in Table 4, as it controls for time-invariant characteristics of cities as well as other measures of urban spatial structure in the same models. We report models focused on income and education segregation separately. Table 5 reports the results of four separate OLS regressions that assess the impacts of changes in different measures of segregation by income on changes in urban spatial structure from 1990 to 2000. The use of year fixed effects means these models control for time-invariant characteristics of cities. Again, changes in cities' circularity (Proximity Index) and their fragmentation (Discontiguity Index) are not statistically significantly related to changes in income segregation.

More generally, urban spatial structure has little explanatory power for low-income households' segregation levels. None of the variables are statistically significant or substantively large. This contrasts with the relatively good fit of the model for overall segregation and high-income segregation, suggesting that the increased isolation of high-income household is driving increases in overall segregation.

The relationship between cities that grew more in terms of land area and overall levels of segregation by income is the most consistent. The variable demonstrates the large influence of high-income segregation. The coefficients imply that the process of urban area expansion affects low- and high-income households differently, but cannot explain whether the process works through a spatial restructuring of low-income households (leaving higher income households more isolated) or enabling higher income household to move away from areas that were more mixed.

We observe a similar pattern with respect to centrality. Cities that grew in a more centralized manner also experienced increases in overall levels of segregation by income, again driven by the isolation of high-income households. This relationship does not elucidate the primary mechanism of spatial re-organization but strongly suggest that it is the relationship of movements into and out of central cities, rather than urban fragmentation or sprawl, which influences how household mobility reorganizes social space.

[2] The correlation coefficient is 0.58 for the period 1990–2000 and 0.47 for the period 2000–2010.

Table 4
Correlations between Changes in Urban spatial structure and Segregation, 1990–2010

Variable	Overall Education	High-Education	Low-Education	Overall Income	High-Income	Low-Income
Population	0.16	0.14	0.13	0.11	0.12	−0.03
Land Area	0.43***	0.36***	0.38***	0.26***	0.27***	0.13
Density	−0.13**	−0.21**	−0.17***	−0.10	−0.07	−0.14
Centrality	0.11	0.04	0.02	0.04	0.13	0.04
Discontiguity	0.15	0.24**	−0.04	0.00	−0.06	0.15
Proximity	−0.02	−0.12	0.13	−0.24**	−0.13	−0.20**

Notes: *, **, and *** indicate statistical significance at the 0.1, 0.05, and 0.01 levels. First three columns (changes in segregation by education) are for 1990–2010 period and second three (changes in segregation by income) are for 1990–2000 period.

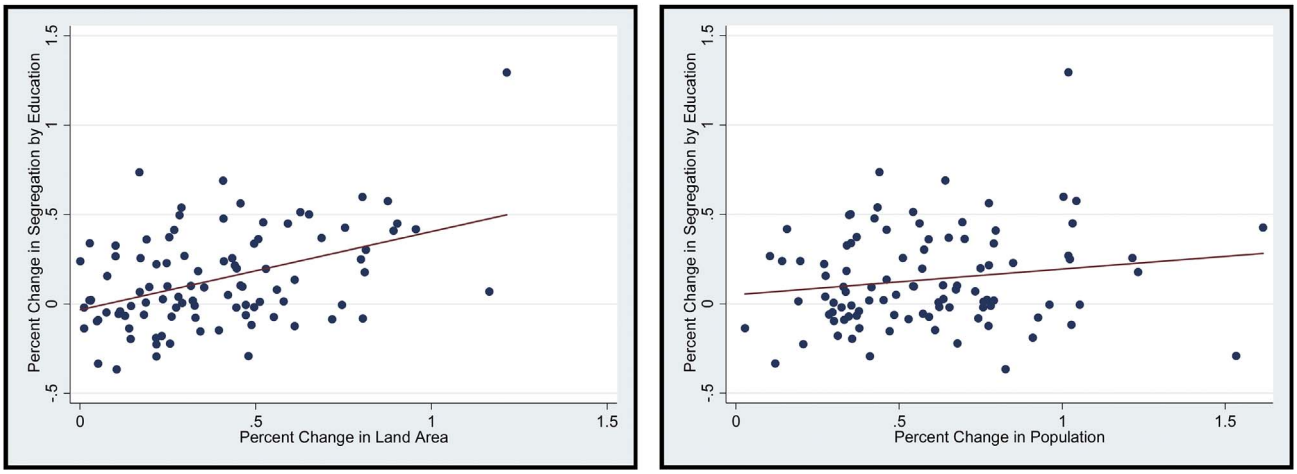

Fig. 1. Urban expansion, population growth and increasing segregation by education.

Table 5
OLS Regressions Results: Changes in Urban spatial structure on Income Segregation.

Variables	Segregation levels			Macro-micro ratio
	Overall Income	Low-Income	High-Income	
Area (ln hectares)	0.0263***	0.008	0.0481***	0.006
	−0.006	−0.006	−0.008	−0.034
Proximity Index	−0.005	−0.005	0.009	−0.036
	−0.005	−0.006	−0.007	−0.032
Discontiguity	0.001	0.006	−0.003	0.013
	−0.003	−0.004	−0.005	−0.021
Centrality Index	0.015***	0.007	0.019***	0.052*
	−0.005	−0.005	−0.007	−0.031
Constant	−0.196***	−0.055	−0.368***	0.081
	−0.047	−0.050	−0.066	−0.289
Observations	193	193	193	193
R-squared	0.47	0.15	0.57	0.082
Number of cities	99	99	99	99
F-statistic	15.49***	3.23*	24.00***	1.58

Notes: *, **, and *** indicate statistical significance at the 0.1, 0.05, and 0.01 levels.

Changes in the macro-micro ratio, which measures the relative scale of segregation, were positively associated with changes in cities' centrality. That means cities that became more centralized, not only increased in overall segregation, they also saw increases in the scale of segregation, with a larger scale of homogeneity in neighborhood composition. This is counter to what might be expected if suburban sprawl is the driving force behind increases in the scale of segregation. The particular kind of urban expansion in large, peri-urban housing developments for working class households was expected to lead to a larger scale of segregation among low-income households. The role of centrality, which consistently impacts segregation, suggest a more complex socio-economic spatial evolution.

As Ward (2009, pp. 114–134) suggests in the case of Mexico City, the movement of lower income household to peripheral, large scale, and homogenous areas is directly connected to the homogenization of high income areas. Traditionally high- and middle-income areas are losing diversity as lower income households move to cheaper, more peripheral areas. Similarly, higher income households moving to newer developments also leads to the rapid increase in segregation at that level. However, it may also be that large suburban developments are more diverse than expected. The assumption is often that only poorer households move to low income neighborhoods, but the income threshold for moving to such areas is unclear. It is possible that the time period does not capture enough of the housing boom, which was primarily after the year 2000, but the results of the subsequent models using data from 2000 to 2010 are similar. Nonehteless, more research on the particularities of centralization and the increasing scale of segregation is needed.

Table 6 reports the results of regression models using four different measures of segregation by education. In this case the time period is longer than that of assessing segregation by income, consisting of two decades (1990–2010) rather than one. More of the urban spatial structure variables are significantly associated with changes in segregation over this longer period, though Discontiguity is not. The overall results differ in important ways from the analysis of income segregation. Where the correlates of income segregation increased in significance when focusing on higher income households, the opposite is true with regards to education. The model fit is best for low-education households indicating income and education function as distinct social cleavages.

Cities that became more compact (as measured by the Proximity Index), saw an increase in the segregation of lower education households, but a decrease in the scale of that segregation, meaning that homogenous neighborhoods were smaller. Urban land expansion is again the most important correlate with segregation. However, unlike

Table 6
OLS Regression Results: Changes in Urban spatial structure on Education Segregation.

Variables	Segregation			Macro-micro ratio
	Overall education	Low-education	High-education	
Area (ln hectares)	0.013***	0.024***	0.016*	−0.065*
	−0.004	−0.005	−0.010	−0.037
Proximity Index	−0.003	0.016**	−0.016	−0.120**
	−0.007	−0.007	−0.015	−0.057
Discontiguity	0.004	0.006	0.009	−0.024
	−0.003	−0.003	−0.007	−0.028
Centrality Index	0.008*	0.009*	0.003	0.125***
	−0.004	−0.005	−0.010	−0.039
Constant	−0.057	−0.189***	−0.054	0.737**
	−0.036	−0.039	−0.080	−0.307
Observations	200	200	200	200
R-squared	0.28	0.58	0.12	0.11
Number of cities	100	100	100	100
F-statistic	7.35***	26.23***	2.69**	2.35**

Notes: *, **, and *** indicate statistical significance at the 0.1, 0.05, and 0.01 levels.

previous tests, the strong connection between urban expansion and increasing segregation is driven more by the segregation of low-education households. As with compactness, greater amounts of urban expansion are associated with a decrease in the scale of segregation. As with income, more centralization is associated with a larger scale of segregation, as well as more segregation itself. These counterintuitive findings are notable and merit further study.

5. Conclusions and future research

Urbanization, especially rapid urbanization without sufficient investment in infrastructure, creates a host of negative externalities, such as congestion, pollution, environmental damage, and the threat of social problems. At the same time, urban expansion is intimately connected to economic growth in most places, and individual productivity is enhanced by living in larger cities (Bertinelli & Black, 2004).

In this study, we focus on one of the most significant costs of urban expansion – social segregation. We assess changes in urban growth, urban spatial structure, and segregation by income and education for the 100 largest cities between 1990 and 2010, using a new data source for 1990 and cutting-edge measures of urban spatial structure and spatial segregation. We find that cities in Mexico have continued to expand rapidly with small increase in population densities, increasing centralization, increasing levels of socioeconomic segregation, and an increase in the geographic scale of that segregation.

We find a strong, positive connection between urban growth (in terms of land area not population) and socioeconomic segregation. There is a negative correlation between urban expansion and the scale of segregation, meaning faster growing cities have smaller pockets of homogeneity. Additionally, we find that greater increases in a Centrality Index, which measures how concentrated population is closer to the center of the city, are positively associated with changes in segregation and the scale of segregation. These last results run counter to expectations from other countries (e.g. Le Goix, 2005), as well as a conceptual model developed from the Mexican experience and observed changes across the country.

In addition, the use of two dimensions of segregation, income and education, highlight important areas for further study. The asymmetry between the driving forces of the two types of segregation, high-income household in one case and low-education household in the other, points to different mechanisms of how differences in economic power are translated into spatial patterns. In both areas, the degree to which segregation is driven by high-income households moving to more homogenous areas and displacing low-income households, is an important area of study for understanding how cities are growing more segregated and implications of segregationist processes. In the United States, recent work has shown that land use regulations generally enacted to exclude lower-income households from more affluent neighborhoods are a driving force behind segregation patterns (Pendall, 2000; Rothwell & Massey, 2010). Moreover, these rules are strongly associated with the isolation of the affluent rather than the concentration of the poor (Lens & Monkkonen, 2016).

The results also highlight a lack of explicit integration of housing market and development dynamics in current research on spatial structure. The mobility of households is intimately tied to new housing development and its role in the supply of housing for different income groups. The way that processes such as filtering[3] and the incremental development of housing (in which growing families can densify a single plot of land and thereby neighborhoods over time, interact and are affected by large scale housing development has been studied to some extent in Mexico (Monkkonen, 2012a). More research on how housing mobility or lack thereof contributes to certain density patterns across cities would be worthwhile.

Moreover, given the changes in the relative commodification of housing through the growth in mortgage lending in Mexico, more research is needed on this topic. Mortgages are restricted based on formal employment, exacerbating one social division, and they also channel households with similar incomes into the same neighborhood. If the government succeeds in making housing markets in Mexico more similar to those in the United States, for example, with higher volume of sales and increasing prices to build equity, this will greatly shape who lives where in cities and therefore density patterns and other aspects of spatial structure.

The study also demonstrates the need for urban researchers to develop a set of metrics and data sources better suited to measuring the particularities of urban spatial structure in Mexico. For example, the Discontiguity Index we use to measure leapfrog development lacks some precision because of the need to rely on census data, and the use of a standard Centralization Index in cities with a prevalence of high-density peri-urban developments is imperfect. Additionally, a multi-scale approach might be useful in the effort to assess changes in urban spatial structure and their relationship to social dynamics. An effort to measure sub-city/neighborhood form dynamics, and then create city-level indexes based on these measures of a smaller geography has the potential to capture the transformations wrought by new, formal housing developments. In terms of data, we need to create a database of state and municipal regulations and planning codes in Mexico, so that we might start to match changes in urban spatial structure to policies other than housing finance. Additionally, better data on transit and road infrastructure, not to mention housing prices, are important for more convincing models.

Finally, in a larger sense, urban scholars in Mexico could usefully focus efforts on understanding and testing whether, how much, and in what ways changes in urban spatial structure matter for people's lives. Research on spatial inequality in the United States and other countries has demonstrated the importance of neighborhood residence through the quality of public services, social networks, and personal safety, for example. In the case of Mexico, one's neighborhood likely also matters in these ways, but we must build an evidence base demonstrating this. An example of this kind of work is Ruiz-Rivera, Suárez, & Delgado-Campos (2016), who demonstrate a lack of access to retail and other urban amenities in highly segregated low-income neighborhoods. This research is important for prioritizing and guiding policy efforts to change spatial structure, which are too often made without research to

[3] Filtering refers to the process of deterioration of housing and how it is often occupied by successively lower-income households. It is more easily observed in cities where supply is elastic with respect to increases in populations and incomes, as higher-income households will tend to move into new housing and leave older units for lower-income households (Rosenthal, 2014).

guide them.

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References

Ahrend, R., Farchy, E., Kaplanis, I., & Lembcke, A. C. (2014). *what makes cities more productive? Evidence on the role of urban governance from five OECD countries.* OECD Regional Development Working PapersOECD Publishing.

Alegría, T. (1994). Segregación socioespacial urbana. El ejemplo de Tijuana. *Estudios Demográficos y Urbanos, 9*(2), 411–428.

Alegría, T. (2008). Interpretación del nuevo patrón de crecimiento urbano y del rol de la planeación en las ciudades de México. *Investigaciones en Ciudad & Arquitectura, 1*, 107–127.

Amindarbari, R., & Sevtsuk, A. (2015). *Metropolitan form analysis toolbox for ArcGIS v. 10.2 and v 10.3.1.* City Form Lab Massachusetts Institute of Technology. Retrieved from http://media.voog.com/0000/0036/2451/files/20150913_MFA_Help.pdf.

Anas, A., Arnott, R., & Small, K. A. (1998). Urban spatial structure. *Journal of Economic Literature, 36*(3), 1426–1464.

Angel, S., Parent, J., & Civco, D. L. (2010a). Ten compactness properties of circles: Measuring shape in geography. *The Canadian Geographer/Le Géographe Canadien, 54*(4), 441–461.

Angel, S., Parent, J., & Civco, D. L. (2010b). *The fragmentation of urban Footprints: Global evidence of sprawl, 1990–2000.* Cambridge, USA: Lincoln Institute of Land Policy.

Ariza, M., & Solís, P. (2009). Dinámica socioeconómica y segregación espacial en tres áreas metropolitanas de México, 1990 Y 2000. *Estudios Sociológicos, 27*(79), 171–209.

Bertinelli, L., & Black, D. (2004). Urbanization and growth. *Journal of Urban Economics, 56*(1), 80–96.

Borsdorf, A. (2003). La segregación socio-espacial en ciudades latinoamericanas: el fenómeno, los motivos y las consecuencias para un modelo del desarrollo urbano en América Latina. In J. L. Luzón, C. Stadel, & C. Borges (Eds.). *Transformaciones regionales y urbanas en Europa y América Latina*. Barcelona: Universidad de Barcelona.

Bosdorf, A., Hildalgo, R., & Vidal-Koppmann, S. (2016). Social segregation and gated communities in Santiago de Chile and Buenos Aires. A comparison. *Habitat International, 54*(1), 18–27.

Delgado, J. (1990). De los anillos a la segregación. La Ciudad de México, 1950–1987. *Estudios Demográficos y Urbanos, 5*(2), 237–274.

Duhau, E. (2003). División social del espacio metropolitano y movilidad residencial. *Papeles de Población, 9*(36), 161–210.

Ford, L. (1996). A new and improved model of Latin American city structure. *Geographical Review, 86*(3), 437–440.

Galster, G., & Cutsinger, J. (2007). Racial settlement and metropolitan land-use patterns: Does sprawl Abet black-white segregation? *Urban Geography, 28*(6), 516–553.

Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H., Coleman, S., & Freihage, J. (2001). Wrestling sprawl to the ground: Defining and measuring an elusive concept. *Housing Policy Debate, 12*(4), 681–717.

Garcia Peralta, B., & Hofer, A. (2006). Housing for the working class on the periphery of Mexico city: A new version of gated communities. *Social Justice, 33*(3), 129–141.

Garza, G. (1999). La Estructura Socioespacial de Monterrey, 1970–1990. *Estudios Demográficos y Urbanos, 14*(3), 545–598.

González-Arellano, S., & Villeneuve, P. (2007). Transformaciones en el espacio socio-rresidencial de Monterrey, 1990–2000. *Estudios Demográficos y Urbanos, 22*(1), 143–178.

Hernández Gómez, E. (2001). Globalización y segregación urbana en Tijuana, Baja California. *Comercio Exterior, 51*(3), 234–242.

INEGI (1990). *Censo de Población Y Vivienda 1990.* Aguascalientes, Aguascalientes, México: Instituto Nacional de Estadística y Geografía.

INEGI (2000). *Censo de Población Y Vivienda 2000.* Aguascalientes, Aguascalientes, México: Instituto Nacional de Estadística y Geografía.

INEGI (2010). *Censo de Población Y Vivienda 2010.* Aguascalientes, Aguascalientes, México: Instituto Nacional de Estadística y Geografía.

Le Goix, R. (2005). Gated Communities: Sprawl and social segregation in southern California. *Housing Studies, 20*(2), 323–343.

Lens, M., & Monkkonen, P. (2016). Do strict land use regulations make metropolitan areas more segregated by income? *Journal of the American Planning Association, 82*(1), 6–21.

Michelini, J. J., & Pintos, P. (2016). Metropolitan expansion and new socio-spatial segregation scenarios in contemporary Argentina. The case of Nordelta-Las Tunas (Buenos Aires). *Habitat International, 54*(1), 40–49.

Mieszkowski, P., & Mills, E. S. (1993). The causes of metropolitan suburbanization. *The Journal of Economic Perspectives, 7*(3), 135–147.

Mills, E. S., & Hamilton, B. W. (1994). *Urban economics* (5th ed.). New York, NY: HarperCollins College Publishers.

Monkkonen, P. (2011a). The housing transition in Mexico expanding access to housing finance. *Urban Affairs Review, 47*(5), 672–695.

Monkkonen, P. (2011b). Do Mexican cities Sprawl? Housing-Finance reform and changing patterns of urban growth. *Urban Geography, 32*(3), 406–423.

Monkkonen, P. (2012a). Housing finance reform and increasing socioeconomic segregation in Mexico. *International Journal of Urban and Regional Research, 36*(4), 757–772.

Monkkonen, P. (2012b). La segregación Residencial En El México Urbano: Niveles Y Patrones. *EURE (Santiago), 38*(114), 125–146.

Monkkonen, P., & Comandon, A. (2016). Urban expansion, segregation, and spatial structure in Mexico. *Ciudades, 111*, 50–59.

Monkkonen, P., & Zhang, X. (2014). Innovative measurement of spatial Segregation: Comparative evidence from Hong Kong and san Francisco. *Regional Science and Urban Economics, 47*, 99–111.

Montejano, J., Monkkonen, P., Guerra, E., & Caudillo, C. (2017). *The costs and benefits of urban Expansion: Evidence from Mexico, 1990-2010.* Lincoln Institute of Land Policy Working Paper.

OECD (2015). *OECD urban policy reviews: Mexico 2015.* Paris: Organization for Economic Co-operation and Development.

Pendall, R. (2000). Local land use regulation and the chain of exclusion. *Journal of the American Planning Association, 66*(2), 125–142.

Puga, D. (2010). The magnitude and causes of agglomeration economies. *Journal of Regional Science, 50*(1), 203–219.

Reardon, S. F. (2009). Measures of ordinal segregation. *Research on Economic Inequality, 17*(1), 129–155.

Reardon, S. F., & Bischoff, K. (2011). Income inequality and income segregation. *American Journal of Sociology, 116*(4), 1092–1153.

Reardon, S. F., & O'Sullivan, D. (2004). Measures of spatial segregation. *Sociological Methodology, 34*(1), 121–162.

Roberts, B. R., & Wilson, R. H. (Eds.). (2009). *Urban segregation and governance in the Americas*. New York, NY: Palgrave-MacMillan.

Rosenthal, S. S. (2014). Are private markets and filtering a viable source of low-income Housing? Estimates from a 'repeat income' model. *American Economic Review, 104*(2), 687–706.

Rothwell, J. T., & Massey, D. S. (2010). Density zoning and class segregation in U.S. metropolitan areas. *Social Science Quarterly, 91*(5), 125–142.

Rubalcava, R. M., & Schteingart, M. (2000). La división social del espacio en las grandes metrópolis mexicanas. Un estudio comparativo. *El Mercado de Valores, 60*(4), 20–33.

Ruiz-Rivera, N., Suárez, M., & Delgado-Campos, J. (2016). Urban segregation and local retail environments. Evidence from Mexico City. *Habitat International, 54*(1), 58–64.

Sabatini, F. (2006). *The Social Spatial Segregation in the Cities of Latin America.* Washington D.C: Inter-American Development Bank.

Sabatini, F., Cáceres, G., & Cerda, J. (2001). Residential segregation pattern changes in main chilean Cities: Scale shifts and increasing malignancy. *Paper presented at the International Seminar on segregation in the city* (pp. 25–28). Cambridge, MA: Lincoln Institute of Land Policy.

SEDESOL (2011). *La expansión de las ciudades: 1980-2010 en México.* Ciudad de México: Secretaría de Desarrollo Social.

Sobrino, J. (1996). Tendencias de la urbanización mexicana hacia finales del siglo. *Estudios Demográficos y Urbanos, 11*(1), 101–137.

Theil, H. (1972). *Statistical decomposition analysis.* Amsterdam: North-Holland Publishing Company.

Ward, P. (2009). *Unpackaging residential segregation: The importance of scale and informal market processes. Vol. 70*, Investigaciones Geográficas, Boletín del Instituto de Geografía, UNAM114.

Winarso, H., Hudalah, D., & Firman, T. (2015). Peri-urban transformation in the Jakarta metropolitan area. *Habitat International, 49*, 221–229.