

FIRM FRAGMENTATION AND URBAN PATTERNS*

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We document several empirical regularities regarding the evolution of urban structure in the largest U.S. metropolitan areas over the period 1980–90. These regularities relate to changes in resident population, employment, occupations, as well as the number and size of establishments in different sections of the metropolitan area. We then propose a theory of urban structure that emphasizes the location and internal structure decisions of firms. In particular, firms can decide to locate their headquarters and operation plants in different regions of the city. Given that cities experienced positive population growth throughout the 1980s, we show that firm fragmentation produces the diverse set of facts documented in the article.

1. INTRODUCTION

The internal structure of U.S. metropolitan areas has evolved dramatically over the last three decades. This evolution exhibits striking patterns that hold for a wide range of cities. If one divides metropolitan areas into a center county and edge counties, employment and residential population have increased both at the center and at the edge. However, over this period, we also observe an important increase in the share of city residents, employment, and establishments at the edge. This shift in economic activity to the edge of the city is more pronounced for nonmanagement occupations than for managers. In addition, the size of establishments decreased in both areas throughout this period. The first part of this article is devoted to documenting these changes in U.S. cities.

What accounts for the evolution of U.S. urban structure over this period? Much of the urban literature attributes the migration of residents to the edge to decreases in transport costs. Explanations of this type, however, are generally not

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consistent with the migration of workers and firms to the edge.² Furthermore, there exists a more fundamental problem with all available explanations for subsets of these phenomena. Specifically, such explanations rely on mechanisms that decrease agglomeration forces at the center thereby explaining how the share of economic activity can increase at the periphery, but not the simultaneous increase in the level of economic activity at the center. These theories are also silent on the issues of functional (management versus nonmanagement) and establishment shifts.³

This article proposes a simple theory aimed at addressing the full set of facts we have just described. The key concept we emphasize relates to firms' ability to break down their production process into headquarters and production plants, where either can locate in different sections of the city: firm fragmentation. Given this margin, we show that increases in population lead to changes in organizational structure such that a larger proportion of firms choose not to integrate their operations.

As city population increases, employment rises at the center and so do center land rents relative to the edge, since land at the center is in fixed supply whereas the periphery encompasses new land as the city expands. The increase in land rents at the center induces firms at that location to break up their operations and keep at the center only those individuals who benefit most from interactions in downtown locations (i.e., those arising from knowledge spillovers or, more generally, production externalities). Thus, the increase in center employment reflects primarily increases in managerial population and, therefore, establishments.

Since each manager at a headquarters supervises several workers, and the production plants of new firms at the center are located more remotely, employment growth is even more pronounced at the periphery. These changes immediately translate into a decline in the share, and a simultaneous increase in the level, of employment in the central region of the city. Because land rents are lower nearer the city's outskirts, population growth also implies that more firms will integrate their operations away from the center. Therefore, increases in population also lead to an increase in managerial employment at the periphery, reinforcing the decline in the share of center employment. Ultimately, however, the combined set of changes resulting from a rise in city population implies a concentration of managers at the center. Furthermore, consistent with the data, rising urban population also leads to a decrease in the share of establishments at the center, and a decrease in establishment sizes as more establishments form part of nonintegrated firms.

² See Anas et al. (1998), and Glaeser and Kahn (2004), for a general review of this literature, and Burchfield et al. (2006) for a recent empirical study of urban sprawl in the United States. As Wheaton (1974) and Brueckner (1987) show, decreases in transport costs, increases in per-capita income, and increases in population each increase residential densities, but not necessarily employment densities, at the edge of an urban area.

³ In theories developed by Fujita and Ogawa (1982) or Lucas and Rossi-Hansberg (2002), a decline in transport costs tends to disentangle the location of business and residential areas and can lead to employment concentration at the center. Because these theories incorporate a richer spatial dimension, the implications of commuting costs, or changes in externality parameters, depend on exactly how one defines the city center. These theories do not incorporate occupational choices or firms' integration decisions.

The objective of the article is in part to underscore, as clearly and cleanly as possible, the usefulness of the firm fragmentation margin in simultaneously explaining diverse changes in urban structure. Thus, our theory abstracts from other urban forces necessary to make the theory a useful quantitative tool. In particular, we assume that managers only control one operation plant, that they need to rent one unit of land per worker, but that headquarters do not use land. These assumptions greatly simplify the analysis, but can be completely or partially relaxed without overturning the substance of our results.

One interpretation of the theory we present, and the empirical evidence more broadly, is that with firms sending their larger and more routine operations to the periphery, city centers are steadily becoming management or administrative hubs. Examples of firms breaking up their operations geographically within a given metropolitan area are ubiquitous across industries. For instance, the Federal Reserve Bank of New York moved its cash and check processing center to neighboring East Rutherford, New Jersey, in 1992; the Washington Post moved its printing operations away from its headquarters in downtown Washington to neighboring Springfield, Virginia, in 1999; the tire manufacturer Michelin, headquartered in Greenville, South Carolina, located its rubber production operations in nearby Anderson County in 2000; and Home Depot is currently moving a distribution center to McDonough Georgia outside Atlanta, the location of its corporate headquarters. More comprehensive evidence related to the physical separation of firm headquarters and production facilities in cities is provided in Henderson and Ono (2008), who also point out that doing so increases the costs of managing plant activities. These costs increase nontrivially with distance but, by locating its headquarters in a metro area, the firm also gains in the ability to gather information.⁴

In a related paper, Chatterjee and Carlino (2001) argue, using a theory of a system of cities, that the deconcentration of U.S. metropolitan employment stems from an increase in aggregate employment. The theory they present is one where an aggregate increase in employment raises densities faster in small metropolitan areas than in larger ones, since large metropolitan areas already have high employment densities and cannot accommodate the new workers cheaply enough. Our article shares with Chatterjee and Carlino (2001) the focus on population growth as the main engine driving the structural change of U.S. cities. In contrast to their work, however, we model a representative city, rather than the interaction between cities, and focus on its internal structure. That is, we study the spatial allocation of employment within a city. We also analyze the location decisions of establishments and agents in different occupations. The new set of facts we uncover leads us to emphasize firms' integration decisions, which we argue can rationalize observed changes in city structure as a result of population growth alone. Chatterjee and Carlino (2001) are not concerned with these integration decisions, nor do they seek to explain the evidence we present. Furthermore, the

⁴ Kim (1999) presents evidence of the increase in firm fragmentation in overall U.S. manufacturing. He argues that firm fragmentation grew significantly between 1958 and 1987. In 1987, 21.9% of firms had multiple plants, and these firms accounted for 73.1% of total employment.

mechanism they emphasize is based on large metropolitan areas becoming congested. In contrast, the fragmentation of the production process that we emphasize does not rely on congestion but on the larger agglomeration benefits that managers experience at the center of larger metropolitan areas.

Along a different line of work, Duranton and Puga (2005) argue that cities have moved from being sectorally specialized to becoming functionally specialized. They contend that decreases in the cost of communication between headquarters and plants have led to the location of headquarters in cities and the location of production plants in smaller towns. Our view of the changes in city structure shares many elements with their work. In particular, Duranton and Puga (2005) also model explicitly the firm's decision to integrate its headquarters and production plants. In their view, this integration decision has implications across metropolitan areas. In fact, we argue that firms' ability to separate headquarters and plants is also key in explaining changes in the internal structure of cities. Our article differs from Duranton and Puga (2005) in that we do not view changes in communication technology as the force underlying changes in urban structure, but instead show that the latter changes emerge simply from rising population. Moreover, our theory suggests that improving communication technology as the only source underlying changes in the internal structure of cities is inconsistent with the evidence we uncover. Aside from changes related to population by location and type, our framework has implications for the share of establishments located in different sections of the city that are consistent with the data. Davis and Henderson (2004) provide evidence that complements our findings. They observe that firms take advantage of services and production externalities (which decline with distance) at the city's business sectors by locating their headquarters at the center and their operation plants elsewhere in the city.

Finally, the notion of shifts in economic activity away from city centers has also been addressed from the standpoint of city governance considerations. Perhaps the most familiar argument is that suburban residents benefit from city-produced public goods and infrastructure (e.g., transportation systems, museums) while at the same time not contributing, or contributing very little, to the financing of such infrastructure. Thus, as cities raise their taxes or lower their public services, because of weak city fiscal institutions or other motives, mobile firms and households leave the city.⁵ Our theory implies a move in economic activity away from city centers quite independently of these fiscal considerations and provides a new dimension to the debate.

The rest of the article is organized as follows. Section 2 presents our data organized in nine different stylized facts. Section 3 presents a simple urban framework that incorporates the firm's integration decision. Section 4 shows that increases in population lead to changes in city structure consistent with the diverse stylized facts we present, and Section 5 concludes.

⁵ See Haughwout and Inman (2002) for a study of this phenomenon and its implications. Interestingly, they show that the resulting loss in scale externalities in city centers feeds back into the performance of suburban locations and adversely affects it.

2. SOME FACTS ON THE EVOLUTION OF CITY STRUCTURE

This section documents a set of regularities in the evolution of city structure that we care to rationalize with the simple theory proposed in this article. We document these facts for the decade spanning the 1980s, although most of the empirical regularities hold from 1970 to 2000. The reason is that for some of these regularities, in particular the ones that involve the location of agents with different occupations, we do not have data covering a longer period. Thus, we chose to homogenize the time period and document our stylized facts over the same decade.

Given our focus on the structure of cities, we separate the city into two locations: center and edge. The center is the area encompassed by the central county of the city. The edge is the set of counties that surround the central county. The central county always includes the central business district of the city, or the downtown area, and is generally much larger than just the downtown area. Our study relies on the 50 largest U.S. metropolitan areas according to their 1999 population. In particular, for each city, we use the most extensive definition of metropolitan area available, either metropolitan statistical area (MSA) or consolidated metropolitan statistical area (CMSA), as defined by the Office of Management and Budget. Our focus on counties as the smallest unit of analysis stems partly from data limitations. One should be cognizant that the size of counties can vary significantly across U.S. cities, which implies that the central county includes a larger fraction of the city in some cases than in others. However, given that our focus is on changes in urban structure, that county definitions did not change during the period we study, and that the facts we document always apply to all or most of the cities under consideration, cross-sectional variations in county size is not a primary concern.⁶

Our data originate from four sources: the Census Bureau “Commute to Work” data, the Census County Business Patterns, the Housing and Urban Development State of the Cities database, and the Bureau of Economic Analysis (BEA) Regional Economic Information System. Importantly, since the theory we propose is that of a city rather than a system of cities, and we wish to abstract from idiosyncratic city characteristics, our analysis focuses only on time changes in city structure during the 1980s, and not on the cross-section of city structures at a given point in time.

2.1. Changes in Absolute Population Levels. The first set of facts we mention is well known. As shown in Figure 1, overall population increased throughout the 1980s in all but one city in our sample. City population growth averaged 21.3% over that period, whereas Pittsburgh’s population contracted by 0.38%. All averages presented in this section are weighted averages using population shares, and are shown as horizontal lines in the bar graphs and circles in the scatter plots. Moreover, population in most cities increased both at the center and at the edge.

To illustrate this point, Figure 2 plots population changes in these areas from 1980 to 1990. In almost all cities, changes are positive both at the center and at the

⁶ We do control for county size when computing the correlation of population growth with changes in urban structure.

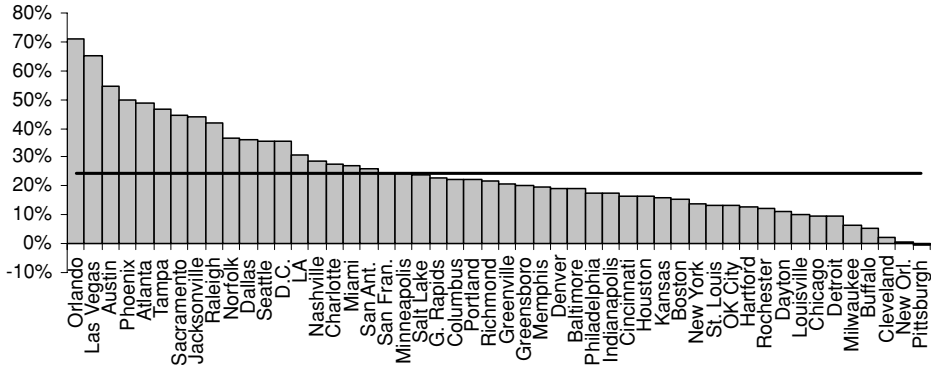


FIGURE 1
POPULATION GROWTH, 1980-90

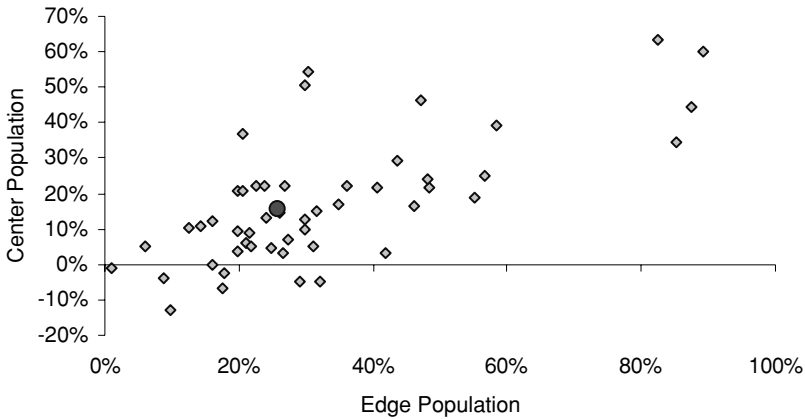


FIGURE 2
POPULATION GROWTH, 1980-90

edge and, for some cities, are very large. The population of Las Vegas, for example, grew by more than 80% in the edge counties and more than 50% at the center. A 1% increase in population at the edge is associated with a 0.6% increase in population at the center. The correlation between changes in population at the center and at the edge is 0.69. All 50 cities in our sample grew in terms of edge population, and only 7 declined in terms of population at the center. In the latter cases, this decline is always small except for New Orleans, whose population fell by 12.8% at the center, but increased by 9.7% at the edge.

Figures 1 and 2 are indicative of overall city population growth, and the fact that this population locates both at the center and in peripheral counties. A question that then arises is: has city population growth led to a change in the link between employment location and residential location? As cities become larger, one might

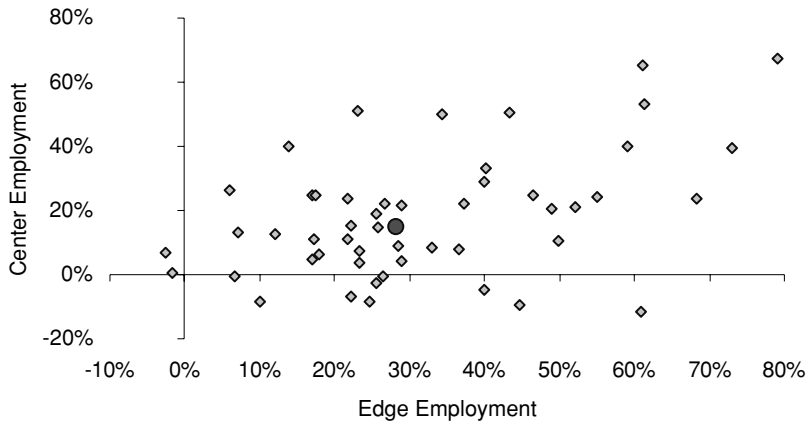


FIGURE 3

EMPLOYMENT GROWTH, 1980-90

expect residential sprawl (i.e., residents locating at the boundary of the city) and employment concentration at the center (see Fujita and Ogawa, 1982; Lucas and Rossi-Hansberg, 2002).⁷ In general, our view of the data is that this phenomenon did not dominate in the United States: Changes in employment are in general paralleled by changes in the number of residents in both areas of the city. A fact consistent with this view is that net commuting between the center and the edge, as a percentage of total population, hardly changed throughout the 1980s. Net commuting represented 8.98% of total MSA population in 1980 and 8.38% in 1990. Average residential growth in the 1980s amounted to 15.4% at the center and 25.7% at the edge. Similarly, average employment growth in the 1980s was 14.8% at the center and 28.3% at the edge. This similarity in the size of changes in employment and residents across city areas is surprising, and suggests that the link between employment and residential location is a key component of urban structure. In addition, this evidence suggests that commuting costs did not decline in any significant way during the 1980s.

Figure 3 depicts employment growth across all cities in our sample (resident growth is identical to population growth, which is presented in Figure 2). The figures indicate that residential population and employment grew in the majority of cities during this period. More specifically, resident and employment growth is positive at the edge in all cities. At the center, employment growth is negative in only nine cities whereas resident growth is negative in only seven cities.

⁷ These models can generate areas at the center in which agents live where they work. However, unless these areas are larger than the central county, larger populations will generally imply more commuting between the center and the edge. Thus, one reason for not finding increased commuting in the data might be that we are aggregating the city in two large areas (the central county and the edge counties).

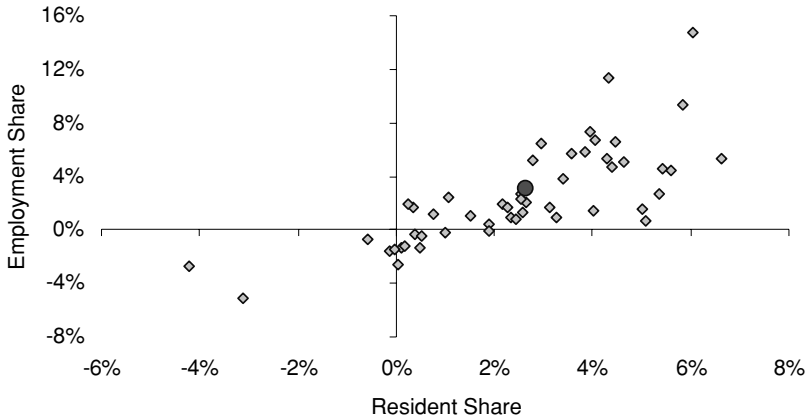


FIGURE 4

CHANGE IN RESIDENT AND EMPLOYMENT SHARE AT THE EDGE, 1980–90

2.2. *Changes in Population Shares across City Areas.* The facts we have just presented relate to absolute, not relative, employment and resident growth. We now address changes in the shares of residents and employment at the edge during the 1980s. Our data show that the shares of both residents and employment have generally increased at the edge. That is, whereas levels grew everywhere, the share of population has shifted from the center to the edge of U.S. cities. The average increase in the share of employment at the edge during the 1980s was 3.11% whereas the average increase in the share of residents at the edge was 2.64%. Put simply, economic activity in the United States is moving to the periphery. Figure 4 depicts changes in resident and employment shares at the edge during this period. It is clear from the graph that in most U.S. cities, the share of individuals who both reside and work at the edge increased.

Given the shift in employment shares toward the periphery, one might wonder whether the increase in edge employment was driven by particular industries. In other words, the facts above could have resulted from specific industries moving away from city centers whereas other industries, perhaps less labor and land intensive, moved to the city center. This does not appear to be the case. The average employment share at the center declined from 0.42 to 0.38 in manufacturing and from 0.47 to 0.43 in services. That is, average employment shares declined by about the same percentage in both sectors.

2.3. *Changes in the Location of Managers.* To gain further insight into the change in employment shares at the center, we examine the change in employment across occupations. In particular, we divide employment into two classes: management and nonmanagement occupations. The first class includes managers and professional workers. The second includes what the Housing and Urban

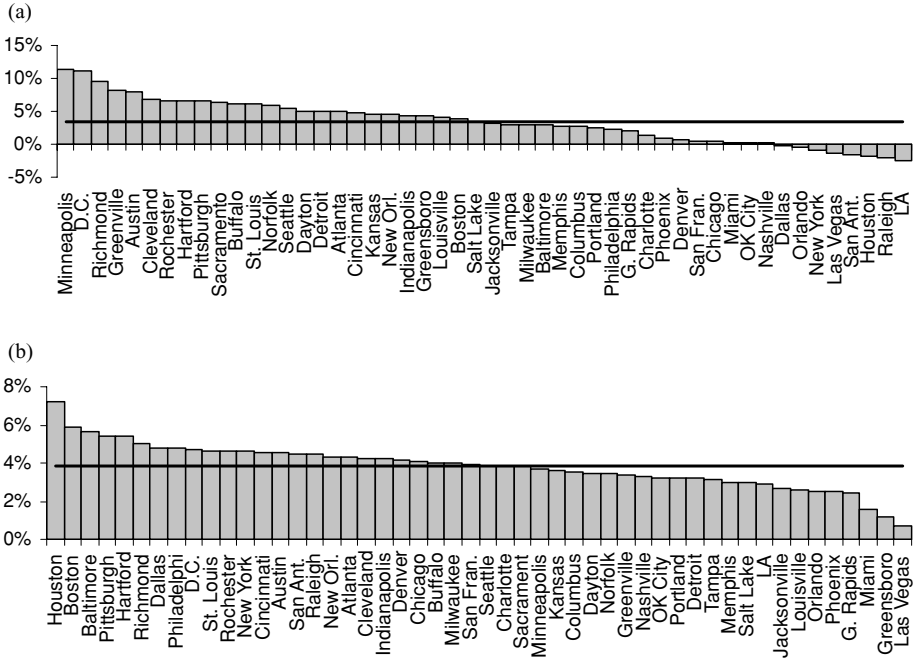


FIGURE 5

- (A) CHANGE IN MANAGEMENT: NONMANAGEMENT RATIO AT THE CENTER RELATIVE TO THE EDGE, 1980–90.
- (B) CHANGE IN TOTAL MANAGEMENT: POPULATION RATIO, 1980–90

Development State of the Cities database classifies as nonmanagement workers.⁸ The latter category includes technicians, sales, administrative support, precision workers, laborers and machine operators, and service workers.

The ratio of managers to nonmanagers at the center increased in all but seven cities in our sample. The average change in this ratio during the 1980s was 10.16%. The ratio of managers to nonmanagers at the edge also rose in all but a handful of cities during this period, with an average increase of 7.48%. Although these facts are informative about changes in city structure, comparisons related to the *relative* location of managers and nonmanagers are also telling. Figure 5(a) compares the change in the ratio of managers to nonmanagers at the center with the change in the same ratio at the edge. Note that the number of managers relative to that of nonmanagers increased more rapidly at the center than at the edge in 84% of the cities throughout the 1980s.⁹ There are only 8 cities (out of 50) where the reverse

⁸ The definition of center and edge in the HUD database differs somewhat from our previous breakdown in terms of counties. These data divide the city into a business center (defined by the geographical city boundary) and the CMSA/MSA area outside of it. For consistency, we extend the business center area to that of the central county, using the assumption that densities of managers and nonmanagers are constant within each area.

⁹ The ratio of managers to nonmanagers increased both at the center and at the edge in every city.

is true. Increases in manager to nonmanager ratios were on average 2.68% larger at the center than at the edge.

In general, therefore, our interpretation of the data is that city centers are becoming management or administrative hubs, with managers heading operation plants at the boundary of the city where land is cheap. In fact, we shall use this interpretation of Figure 5(a) in the model we develop below. Observe that although managers were generally more concentrated in city centers throughout the 1980s, every single city over this period saw an increase in the overall ratio of managers to population. In other words, cities as a whole are also evolving toward administrative functions. Figure 5(b) illustrates the change in the ratio of management to population, with a mean of approximately 4.13% across all cities. The evidence presented in Figure 5(b) only reinforces the findings in Duranton and Puga (2005), who argue for the functional specialization of cities.

2.4. Changes in the Location and Characteristics of Establishments. Having set out some facts regarding changes in population location within U.S. cities, we now turn to the location of establishments in different parts of the city. Consistent with overall population and employment growth throughout the 1980s, the number of establishments also increased in all but three U.S. cities, both at the center and at the edge. The number of establishments grew on average by 30.1% at the center and by 50.5% at the boundary. Hence, although the net entry of firms or plants is more pronounced at the city edge, firm entry is also substantial at the center. The correlation between establishment net entry at the center and edge is 0.45.

Figure 6 illustrates these changes. Note that in some cities, net entry of establishments at the edge exceeds 80% over our sample period and, in some cases, reaches as high as 110%. Although central counties experienced significant net establishment entry throughout the 1980s, more establishments located at the boundary

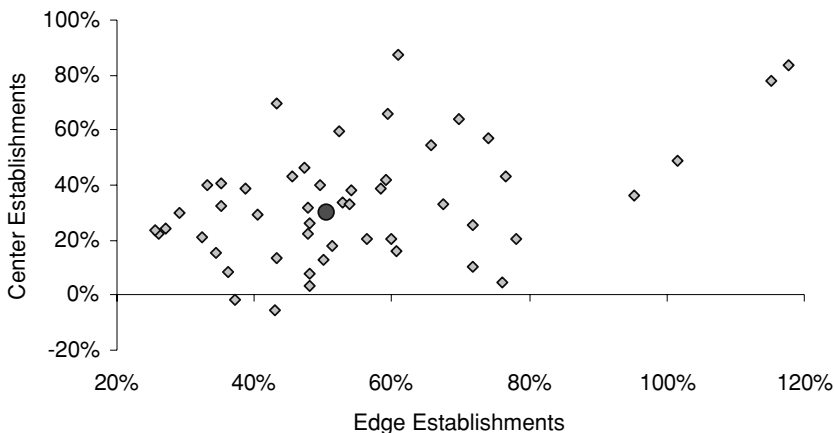


FIGURE 6

ESTABLISHMENT GROWTH AT THE CENTER AND AT THE EDGE, 1980–90

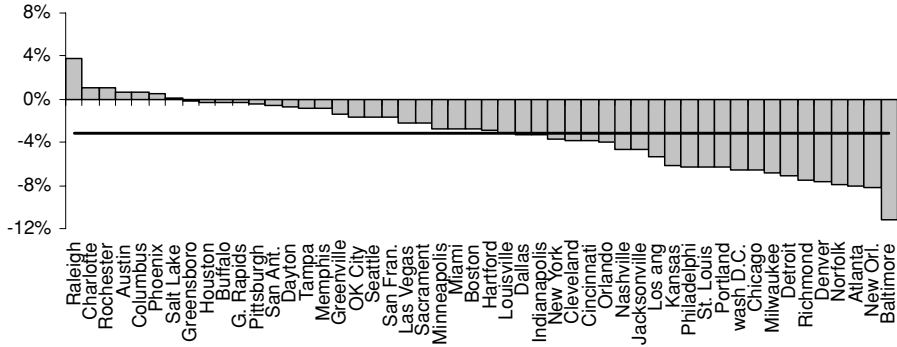


FIGURE 7

CHANGE IN ESTABLISHMENT SHARE AT THE CENTER, 1980-90

over that period. Indeed, the change in the share of establishments at the center is negative in all but a few cities, as Figure 7 illustrates. The average change in the share of establishments located at the center is -3.65% . In 64% of the cities, the share of establishments was larger at the center than at the edge in 1980, with an average establishment share of 54.9% at the center. Therefore, although more than one half of the establishments were located at the center in 1980, many new firms chose to locate near the city’s outskirts during the subsequent decade, which led to a significant decrease in the share of firms residing at the center.

How were establishment sizes, measured in number of employees, affected during this period? In general, we find that establishment sizes declined over the 1980s. This finding is consistent with other evidence in the literature regarding the average size of firms in the United States (see Garicano and Rossi-Hansberg, 2006). Establishment sizes declined on average by 4.08% at the center and 3.92% at the edge. Figure 8 shows changes in establishment sizes both at the center and at the edge. We can see that for most cities, establishment sizes fell in both regions. This finding, however, does not hold for all cities.

About half of the cities in our sample experienced a decline in average establishment size in both regions simultaneously. Establishments tend to be larger at the center than at the boundary, with 21.4 employees per establishment at the center versus 17.1 employees per establishment at the edge in 1980.

The last characteristic of urban economic activity that we wish to establish in this section concerns the relationship between changes in the number of managers and the number of establishments across cities. Figures 9(a) and (b) illustrate this relationship. Observe that the number of establishments and managers are highly correlated: The correlation is 0.81 at the center and 0.62 at the edge. At the center, a 1% increase in the number of managers is associated with a 0.89% increase in the number of establishments, where the fit is characterized by a surprisingly large R^2 statistic, 0.65. In contrast, at the edge, a 1% increase in the number of managers is associated with only 0.57% more establishments, with the relationship having a much lower R^2 . This evidence suggests that the number of establishment per

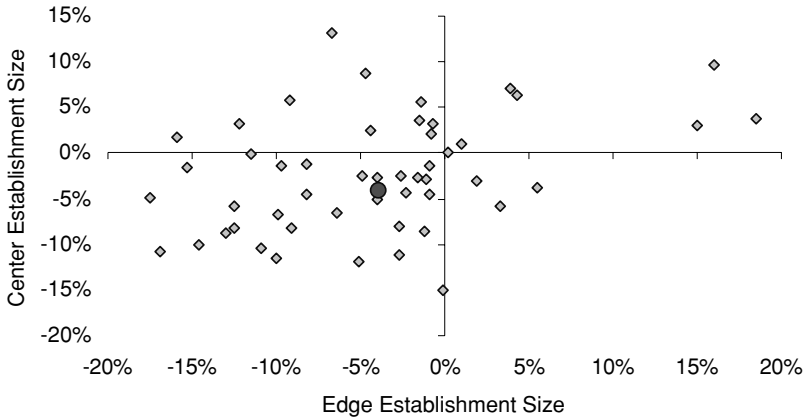


FIGURE 8

CHANGE IN ESTABLISHMENT SIZE AT THE CENTER AND AT THE EDGE, 1980-90

manager at the center is larger than at the edge, and that changes in the number of establishments are more tightly related to changes in managers at the center than at the edge. Although our measure of managers also includes professional workers, the fact that managers and establishment are so closely linked gives us some confidence that many of these agents are in fact performing administrative or managerial roles.

2.5. Stylized Facts on Urban Structural Change. We now summarize the set of stylized facts presented for the 50 largest U.S. cities over the 1980-90 decade. Throughout the article, we shall refer to these stylized facts by the number we assign to each below.

1. Overall population growth.
2. Resident population growth at the center and at the edge of cities.
3. Employment growth at the center and at the edge of cities.
4. A similar reduction in resident and employment shares at the center.
 - a. Present both in services and manufacturing.
5. City centers increasingly becoming management or administrative hubs:
 - a. An increase in the ratio of managers to nonmanagers at the center compared to the same ratio at the edge.
 - b. An increase in the total number of managers relative to total employment.
6. An increase in the number of establishments at the center and at the edge of cities.
7. A decline in the establishment share at the center.
8. A decline in establishment size both at the center and at the edge of cities.

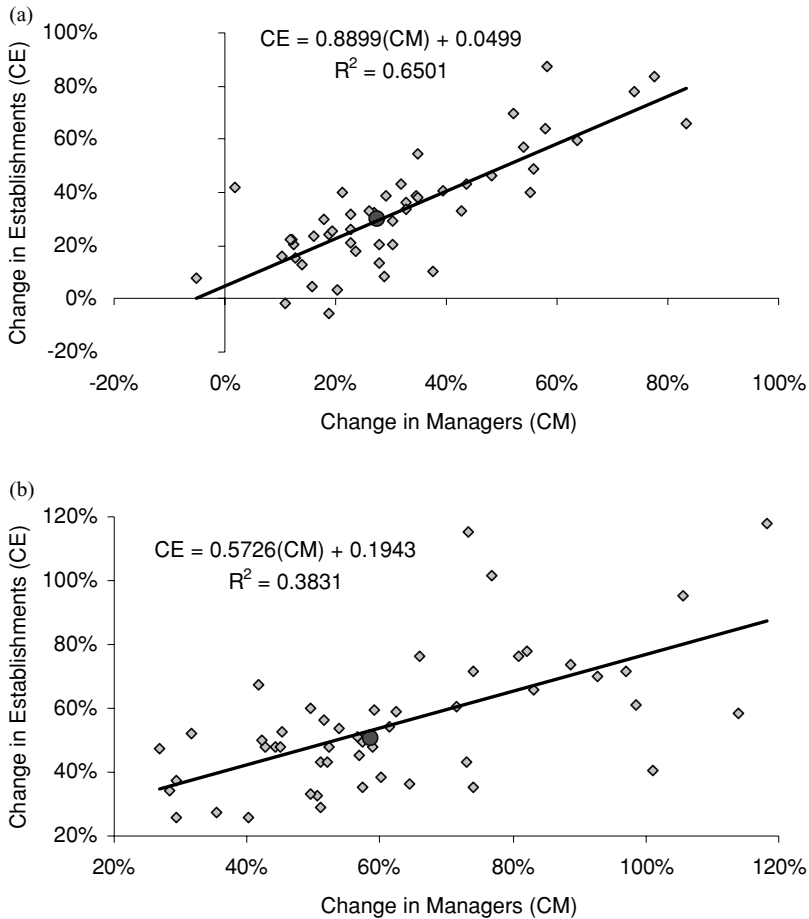


FIGURE 9

(A) CHANGE IN MANAGERS AND CHANGE IN ESTABLISHMENTS AT THE CENTER, 1980–90. (B) CHANGE IN MANAGERS AND CHANGE IN ESTABLISHMENTS AT THE EDGE, 1980–90

9. The number of establishments and managers are more tightly related at the center than at the edge.

In the next section, we propose a simple model of city structure and explain how Fact 1 alone can lead to stylized Facts 2–9. Put another way, it is possible to think of the changes in residents, employment, occupations, and establishments described above as the result of urban population growth. At the heart of the theory we present lies a decision on the part of firms to either integrate their operations in one location or separate them into headquarters and production plants. We argue that adding this additional margin to urban models is crucial in explaining the diverse set of changes observed in the internal structure of U.S. cities.

3. THE MODEL

This section presents a theory of the internal structure of cities simple enough to remain analytically tractable yet rich enough to address the diverse set of facts outlined in the previous section. Since our goal is to illustrate the main forces that lead to these empirical regularities, we model cities as consisting of only two areas: the center of the city and what we call the edge. We think of these two areas as the model equivalent of the central and edge counties in the data. Given this parallel, we assume that the central area of the city is given exogenously by $L_c > 0$. The edge area is endogenous, and we denote it by $L_b > 0$, where b stands for the city boundary. We assume that residential land rents at the edge are given by an agricultural land rent, $\bar{R} \geq 0$, which represents its opportunity cost. Land rents at the center of the city are endogenous and determined in equilibrium. Total city population, P , is exogenously given. In fact, we shall argue below that the theory we develop can rationalize the set of stylized facts presented above simply as the result of population growth. Our theory, therefore, is a partial equilibrium theory that takes as given two key elements from national economic behavior, namely, agricultural land rents and city population sizes. Any theory of city structure must take a stand on the variables to be determined at the aggregate rather than the city level, and our choice is driven by the set of facts that we seek to explain.

The key insight of our model is that allowing firms to separate their location into headquarters and production plants implies that city growth leads to a set of empirical regularities regarding urban structure. Headquarters develop knowledge and, therefore, experience external effects from other headquarters. Knowledge transactions are carried out in headquarters that tend to agglomerate in high rent areas of the city. Production plants, in contrast, carry out more routine tasks that do not lead to knowledge spillovers and, consequently, tend to locate in areas where land rents are low. Production plants in our framework can be interpreted as either manufacturing plants, retail stores, or other production facilities.

3.1. *Firms.* The city produces and consumes one good, the price of which we normalize to one. A firm is made up of a manager who hires workers to produce. The manager and her workers can locate at either the center or the edge of the city. We refer to the location of the manager as the firm's headquarters and the location of her workers as the firm's production plant. The number of workers a manager can hire is determined by whether the firm is located in only one location (an integrated firm) or whether the headquarters and production plants reside in different locations. In the former case, the manager finds it less costly to communicate and interact with workers that are located close by so that she can oversee a larger set of workers, $n_{cc} = n_{bb} = \alpha\delta > 1$, where n_{ij} denotes the number of employees of a firm with headquarters in area i and production plant in area j . In contrast, if the manager decides to set up a nonintegrated firm, she needs to spend additional resources to monitor and interact with her workers, who are physically removed, and her span of control is given by $n_{cb} = n_{bc} = \alpha\delta > 1$, where

$\delta < \bar{\delta}$, and α can be interpreted as the level of communication technology.¹⁰ This assumption is motivated by Fact 9 above. In other words, in the data, changes in the number of managers are clearly positively correlated with changes in the number of establishments both at the center and at the edge. In fact, the correlation between changes in managers and changes in the number of establishments is significantly higher at the center than at the edge in the 1980s, which is consistent with a constant number of managers per firm (abstracting from composition effects that are not present at the center).¹¹

In our model, the location of a firm's headquarters matters significantly in that it determines its productivity. In particular, firm productivity depends on the number of managers located in the area of the city where the firm's headquarters are located: a production externality. We assume that the production externality is related only to the number of managers and not to the number of workers. We have in mind a knowledge spillover that naturally affects "knowledge workers," which we identify as managers and professional workers in the data. However, for the purpose of the theory, the only important distinction is that there be some firm employees that benefit from knowledge spillovers and others that do not. Hence, should the firm break up its operations geographically, it will keep the individuals that benefit most from knowledge spillovers in the location where those effects are largest.

Total output of a firm with headquarters in area i and production plant in area j is given by $AE_i n_{ij}$, where E_i denotes the number of managers in i and A is a city-wide productivity parameter. A firm has to pay labor costs given by a city-wide wage $w > 0$ (since all agents in the city are assumed identical) times the number of workers it hires, n_{ij} , as well as land rents. We assume that the firm needs to hire one unit of land per worker in order to operate, so that total land rent paid by this firm is given by $R_j n_{ij}$.¹² Firms are owned by managers whose earnings are given by firms' profits. It follows that a manager who owns the firm we have just described earns

$$F_{ij} = (AE_i - w - R_j)n_{ij}.$$

The problem of a manager is then to choose the location of the firm's headquarters and production plant to solve

¹⁰ Observe that the notion of spatial structure here is entirely defined by the parameters α , $\bar{\delta}$, δ and L_c . In principle, center and edge might refer to Manhattan and Philadelphia rather than Manhattan and Queens. However, absent other forces, firms would choose to build their plants as close as possible to headquarters conditional on land rents. Although the facts in this article relate only to the internal structure of cities, it would be interesting to explore these dimensions across cities as well.

¹¹ See Garicano (2000), and Garicano and Rossi-Hansberg (2006) for organizational models that yield smaller team sizes as communication costs increase.

¹² Note that managers do not require land. Relaxing this assumption implies that we need to relax some other assumption as well, since employment at the center is otherwise fixed by the amount of land at that location. One possibility is to allow for some substitution between land and labor.

$$(1) \quad \begin{aligned} \bar{F} &= \max_{ij} \{F_{ij}\} \text{ for } i, j \in \{c, b\} \text{ and subject to} \\ n_{ij} &= \begin{cases} \alpha \bar{\delta} & \text{if } i = j \\ \alpha \underline{\delta} & \text{if } i \neq j. \end{cases} \end{aligned}$$

Put alternatively, managers decide whether to locate at the center or at the edge of the city and, from that location, whether to operate integrated or separate production facilities.

3.2. Individuals. A population P of identical agents lives and works in the city. Agents consume the only good produced in the city and live where they work. The latter assumption is justified by the fact that in the data, employment and residents in both areas of the city have moved to the edge in similar proportions, as summarized in Fact 4. Recall also that the share of net commuters between the center and edge stayed remarkably constant throughout our sample period. Hence, although commuting is potentially important in explaining the cross-section of urban structures in the United States, it is not a driving force underlying observed changes, at least at the level of aggregation of our analysis (namely the county level).¹³

Consumers order consumption according to a linear utility function. Therefore, given that the price of consumption goods is normalized to one, they solve

$$(2) \quad U = \max \{ \bar{F}, w \}.$$

Since all agents are identical and, in equilibrium, some agents become managers whereas others become workers, $\bar{F} = w$. Furthermore, the fact that all agents have the option to set up integrated or nonintegrated firms in any set of locations yields, in equilibrium, $\bar{F} = F_{ij}$ for all operating firms with headquarters in i and production plants in j .¹⁴

3.3. Equilibrium. We denote by E_{ij} the number of managers operating firms with headquarters in i and operation plants in j . Hence, the total number of managers at location i , E_i , is given by

$$(3) \quad E_i = E_{ii} + E_{ij}.$$

¹³ One could extend the model following Wheaton (1974), Brueckner (1987), or Lucas and Rossi-Hansberg (2002) to include endogenous continuous residential densities and commuting. However, this fact indicates that by adding these features, not much would be gained in terms of the ability of the model to explain the dynamics of urban structure in the United States, although they would complicate the theory significantly.

¹⁴ We abstract from differences in human capital or ability that may lead to differences in wages or managerial rents. These differences, however, would leave our findings on city structure unchanged when expressed in efficiency units of labor. If managers are the most talented individuals, wages at the center would be greater than at the edge. Note also that the particular agglomeration force at work is not essential. One might have assumed that managers prefer to live close to each other and obtained similar findings.

Since the number of units of land at the center is exogenously given by L_c and firms rent one unit of land per worker, the number of workers at the center is given by

$$(4) \quad L_c = E_{cc}n_{cc} + E_{bc}n_{bc}.$$

Analogously, the number of workers at the edge is also given by the number of units of land used at the boundary,

$$(5) \quad L_b = E_{cb}n_{cb} + E_{bb}n_{bb}.$$

Land use at the edge, however, is endogenous, and the area occupied by the city expands or contracts as the economic environment changes. It follows that the total number of workers in the city is given by $W = L_c + L_b$. Total city population is given by these workers plus those individuals who become managers of firms with headquarters at the center and at the edge. Therefore, labor market equilibrium requires that

$$(6) \quad E_c + E_b + W = P.$$

We are now ready to define a competitive equilibrium for this city:

A competitive city equilibrium is a set of scalars $\{E_c, E_b, E_{cc}, E_{bb}, E_{cb}, E_{bc}, L_b, R_c, w, \bar{F}, F_{cc}, F_{bb}, F_{cb}, F_{bc}\}$ such that:

1. *Agents solve (2), managers solve (1), and $w = \bar{F} = F_{ij}$ for all firms of type ij that operate in location, $i, j \in \{c, b\}$.*
2. *Equilibrium conditions (3), (4), (5), and (6) are satisfied.*
3. *Population size is given by P , land available at the center by L_c , and land rents at the boundary by $R_b = \bar{R}$.*

The number of establishments at the center is given by

$$(7) \quad S_c = \underbrace{E_{cc} + E_{cb}}_{E_c} + E_{bc},$$

where S_c counts integrated production units at the center, E_{cc} , headquarters at the center used by managers who operate plants in the periphery, E_{cb} , and production plants at the center run by managers residing at the boundary, E_{bc} . Similarly, the number of establishments at the edge is defined as

$$(8) \quad S_b = \underbrace{E_{bb} + E_{bc}}_{E_b} + E_{cb}.$$

Within the framework of our model, average establishment sizes at the center and at the edge are given by $(L_c + E_c)/S_c$ and $(L_b + E_b)/S_b$, respectively. Establishments are of only three sizes: size 1 in the case of

headquarters of nonintegrated firms, size $\alpha\delta$ in the case of the operation plant of a nonintegrated firm, and size $1 + \alpha\delta$ in the case of integrated firms.

The model we have just laid out potentially yields different types of equilibria. These types correspond to different sets of firms (i.e., integrated or not) operating in different areas of the city. The fact that spans of control differ across integrated and nonintegrated firms rules out equilibria where all types of firms coexist. In essence, if differences in spans of control are such that a firm finds worth it to locate its headquarters at the center and its production plant at the edge, then the reverse cannot be true. We formalize this result in the next proposition. Proofs of all propositions are included in the Appendix.

PROPOSITION 1. *There are no equilibria where both integrated and nonintegrated firms operate at all locations.*

Of the remaining cases, the one corresponding to the type of city encountered in the data has most headquarters locating at the center (which in fact defines what we call the center and what is defined as a central county in the data). We now show that this case exists as an equilibrium of our model under a mild parameter restriction. In this equilibrium, there are no firms whose headquarters are at the edge but whose production plants reside at the center. Thus, the equilibrium we have just described is such that

$$(9) \quad \bar{F} = F_{cc} = F_{cb} = F_{bb} = w \quad \text{and} \quad F_{bc} < \bar{F},$$

so that $E_{cc}, E_{cb}, E_{bb} > 0$ and $E_{bc} = 0$. Because land rents are much lower at the edge than at the center in the data, firms that have operation plants at the center and headquarters at the edge are indeed very rare. Perhaps the most compelling reason to focus on this type of equilibrium is Fact 9. This fact shows that the number of managers is very tightly connected to the number of establishments, especially at the center, where the number of managers and establishments move almost one for one in Figure 9(a). In fact, in the model equilibrium with $E_{bc} = 0$, the number of establishments and managers does move one for one at the center since $S_c = E_c$ from (7). This will not be the case at the edge, however, as $S_b = E_b + E_{cb}$ in (8), where E_{cb} captures establishments that are stand-alone operation plants. As in Fact 9, therefore, this equilibrium of the model implies that changes in managers are less closely related to changes in establishments at the edge than at the center. Thus, we prove all results below only for this case.

Another candidate equilibrium one might have chosen to highlight relates to the case where $E_b = 0$. In other words, managers only locate at the center. This indeed constitutes an equilibrium and it has almost identical properties to the one we study in the text with $E_b > 0$. The only key difference is that, when $E_b = 0$, the size of establishments at the edge is constant so that we cannot study changes in establishment size at that location. Apart from this implication for establishment

size at the edge, however, all other propositions we prove below hold unchanged for this case. Because we do observe managers and workers in all locations in the data, we prefer to present the case with $E_b > 0$.¹⁵

3.4. *Equilibrium Allocation.* Given the restriction $E_{bc} = 0$, we now construct an equilibrium allocation for our model. From (3), we know that $E_b = E_{bb}$ since $E_{bc} = 0$, and that $E_{cb} = E_c - E_{cc}$ where, by Equation (4), $E_{cc} = L_c/(\alpha\bar{\delta})$. Then, the number of workers in the city is given by

$$L_c + L_b = W$$

so that

$$(10) \quad L_c \left(1 - \frac{\delta}{\bar{\delta}} \right) + E_c \alpha \underline{\delta} + E_b \alpha \bar{\delta} = W.$$

Condition (9) implies that integrated and nonintegrated firms at the center earn equal profits,

$$(11) \quad (AE_c - w - R_c) \alpha \bar{\delta} = (AE_c - w - \bar{R}) \alpha \underline{\delta},$$

as do integrated firms across locations,

$$(AE_c - w - R_c) \alpha \bar{\delta} = (AE_b - w - \bar{R}) \alpha \bar{\delta}.$$

These relations implicitly link the number of managers working at the center and boundary according to

$$(12) \quad E_b = E_c + \frac{\bar{R} - R_c}{A}.$$

Equality between rents and wages then implies that

$$(13) \quad (AE_c - w - R_c) \alpha \bar{\delta} = w.$$

From Equations (11) and (13), we further have that

$$(AE_c - w - R_c) \alpha \bar{\delta} = w = (AE_c - w - \bar{R}) \alpha \underline{\delta}.$$

¹⁵ Because our theory is static, there is no immediate way of discriminating between equilibria using a stability argument. However, depending on the assumed laws of motion for workers, one might potentially argue that the equilibrium with $E_b = 0$ is the stable equilibrium. Should this be the case, all our findings, apart from establishment size at the edge, go through unchanged.

Consequently,

$$(14) \quad \bar{R} - R_c = \left(\frac{1}{\alpha\bar{\delta}} - \frac{1}{\alpha\underline{\delta}} \right) w = - \underbrace{\left(\frac{\bar{\delta} - \underline{\delta}}{\alpha\bar{\delta}\underline{\delta}} \right)}_{\Lambda < 0} w,$$

so that $R_c > \bar{R}$ under our maintained assumption regarding the span of control, $\bar{\delta} > \underline{\delta}$. That is, land rents are larger at the center than at the edge, an implication that follows from the assumption that $E_{bc} = 0$. The fact that most cities see land rents decrease as one moves away from the center is well known and reinforces our focus on an equilibrium with this feature. Note that the difference in land rents is simply the difference in managers per worker between integrated and nonintegrated firms times the city wage. Hence, when different types of firms coexist in equilibrium, the advantage that an integrated firm gains by locating at the center in terms of lower management costs (i.e., a low manager/worker ratio) is offset by higher rents at that location.

From Equation (13), and substituting for R_c using (14), we obtain, after some manipulations,

$$(15) \quad E_c = \frac{1 + \frac{1}{\alpha\bar{\delta}}}{A} w + \frac{R_c}{A} = \frac{1 + \frac{1}{\alpha\bar{\delta}}}{A} w + \frac{\bar{R}}{A},$$

which implies $E'_c(w) > 0$; the number of managers at the center increases with city wages. Using (14) and Equation (12), we can solve for the set of managers at the edge as a function of wages,

$$(16) \quad E_b = E_c + \left(\frac{\Lambda}{A} \right) w = \frac{1 + \frac{1}{\alpha\bar{\delta}}}{A} w + \frac{\bar{R}}{A}.$$

Therefore, the number of managers at the edge also increases with wages, but at a slower rate since the rent differential increases with wages and creates incentives for firms to locate workers at the boundary and managers at the center.

Now consider the market clearing Equation (6) given by

$$L_c \left(1 - \frac{\delta}{\bar{\delta}} \right) + E_c \alpha \underline{\delta} + E_b \alpha \bar{\delta} = W = P - E_c - E_b.$$

Substituting for the number of managers in both regions, the demand for workers becomes

$$(17) \quad W = L_c \left(1 - \frac{\delta}{\bar{\delta}} \right) + E_c \alpha \underline{\delta} + E_b \alpha \bar{\delta}$$

$$(18) \quad = L_c \left(1 - \frac{\delta}{\bar{\delta}} \right) + \left(\frac{\alpha \underline{\delta} + \alpha \bar{\delta}}{A} \right) \bar{R} + \frac{2 + \alpha \underline{\delta} + \alpha \bar{\delta}}{A} w,$$

which is linear and increasing in profits or wages (w). Since higher profits resulting from greater externalities are associated with more managers in both areas of the city, the demand for workers increases as profits rise. The supply of workers is given by

$$(19) \quad P - E_c - E_b = \left(P - \frac{2\bar{R}}{A} \right) - \frac{2 + \frac{1}{\alpha\bar{\delta}} + \frac{1}{\alpha\bar{\delta}}}{A} w,$$

which again is linear but decreasing in profits or wages (w). Because larger profits motivate more agents to become managers, the supply of workers decreases with profits. The equilibrium wage can then be found by equating (17) and (19). That is

$$AP - AL_c \left(1 - \frac{\delta}{\bar{\delta}} \right) - (2 + \alpha\bar{\delta} + \alpha\bar{\delta}) \bar{R} = \left(4 + \alpha\bar{\delta} + \alpha\bar{\delta} + \frac{1}{\alpha\bar{\delta}} + \frac{1}{\alpha\bar{\delta}} \right) w$$

so that city wages are given by

$$(20) \quad w = \frac{AP - AL_c \left(1 - \frac{\delta}{\bar{\delta}} \right) - (2 + \alpha\bar{\delta} + \alpha\bar{\delta}) \bar{R}}{4 + \alpha\bar{\delta} + \alpha\bar{\delta} + \frac{1}{\alpha\bar{\delta}} + \frac{1}{\alpha\bar{\delta}}}.$$

With the equilibrium wage in hand, we can solve for all equilibrium variables of the model. For the comparative statics in the next section, it is helpful to denote the denominator of (20) as $D > 0$. An equilibrium of the type in which we are interested exists only if

$$(21) \quad \frac{P}{L_c} > \left(1 - \frac{\delta}{\bar{\delta}} \right) + \frac{(2 + \alpha\bar{\delta} + \alpha\bar{\delta}) \bar{R}}{AL_c},$$

which ensures that $w > 0$. This restriction essentially requires city population densities that are large enough to make the creation of a city profitable given land rents at the edge. Population densities must also be large enough so that agglomeration effects guarantee that some nonintegrated firms' headquarters choose to locate at the center. The following proposition obtains directly from the equilibrium wage derived above.

PROPOSITION 2. *The equilibrium wage, w , is an increasing function of population size, P , and city-wide productivity, A . It is a decreasing function of the supply of land at the center, L_c , the span of control parameter, α , and edge land rents, \bar{R} .*

Note that the wage increases with population size. Although this finding matches the fact that wages are generally higher in larger cities, it nevertheless seemingly conflicts with the standard intuition that wages fall as the supply of workers increases. There are two characteristics of our setup that contribute to overturning this intuition. First, the wage is the compensation of workers, but since all agents

in the city are identical, it also represents profits of entrepreneurs or managers. Hence, since an increase in overall population creates new managers, the demand for workers also increases. Second, the production externality in our framework implies that the more managers operate in a given location, the higher the productivity (output per worker) of all firms in that location. As population grows, and more firms operate in the city, this effect contributes to raising manager rents and worker wages. As we have just mentioned, the prediction regarding wages and city size can be directly contrasted with data. In 2003, for instance, the average wage in the largest five cities in our sample was \$42,976, as compared to just \$34,340 for the five smallest cities.¹⁶

The effect of the model's other parameters on wages are more standard. Wages increase with city-wide productivity and decrease with the amount of land available at the center. The latter result reflects the fact that more firms at the center become integrated as L_c rises. This effect reduces the number of managers per worker at the center and, therefore, externalities in that location and manager profits (wages). As rents at the boundary increase, the advantage of setting up a nonintegrated firm falls, which again reduces externalities at the center and wages. Finally, as firms' span of control, α , increases, firms become larger, less agents become managers, and externalities fall along with wages and managerial rents (more on the effect of α in Section 5.2).

4. ADDRESSING THE STYLIZED FACTS

This section shows that the model we have developed naturally leads to the changes in city structure laid out in Section 2. From Fact 1, we know that population growth was positive in virtually all cities in our sample. Recall that the first set of facts referred to population size both at the center and at the edge. Since, in our model, agents live and work in the same location, the model's predictions concerning the growth in residents and employment are identical. Therefore, if we can show that as population grows, employment increases both at the center and at the edge (Fact 3), then the model will immediately satisfy Fact 2.

To address Fact 3, observe that two effects emerge as population grows. First, the number of managers at the center increases, as a result of the rise in agglomeration effects, which raises population at the center (recall that the worker population at the center is pinned down at level L_c by assumption). Second, since managerial population also increases at the boundary with urban growth, again as a result of larger externalities, so does the number of workers given the fixed span of control. Therefore, total employment must also increase at the edge. A portion of the additional workers at the boundary will work for managers that head firms with headquarters at the center. Ultimately, this reasoning implies that the model is consistent with Fact 2.

Total employment at the center and at the edge is given by $E_c + L_c$ and $E_b + L_b$, respectively. Simple differentiation then leads to the following

¹⁶ See Lee (2005) for recent evidence on the urban wage premium.

proposition, consistent with Facts 2 and 3. All proofs in this section are relegated to the Appendix.

PROPOSITION 3. *An increase in population implies an increase in total employment at the center, $E_c + L_c$, and at the edge, $E_b + L_b$.*

The proposition above provides conclusions regarding the level of employment in both areas of the city. However, we are equally interested in the share of employment in each area. We have already argued that as population grows, managerial population increases at the center. All new center managers, however, lead nonintegrated firms. The reason is that the number of workers at the center cannot expand given the fixed amount of land and the technology that requires one unit of land per worker. Managers choose nonintegrated rather than integrated firms because rents at the boundary do not grow with population, since they are pinned down by the opportunity cost of land, \bar{R} . At the same time, since the center land area of the city is constant, the price of land increases at the center, which again motivates some managers to send their operation plants to the edge. In fact, rents at the center rise such that the number of center managers who choose to operate integrated firms remains constant, which must hold in order for land markets to clear. We can show that given a large enough population share at the center, the increase in center employment (caused solely by the increase in managerial population) is always smaller than the increase in managers and workers at the edge. This result implies that the employment share at the center falls with population growth, consistent with Fact 4. We formalize this reasoning in the next proposition.

PROPOSITION 4. *An increase in population implies a decrease in the employment share at the center, $\frac{E_c + L_c}{P}$, if and only if*

$$\frac{E_c + L_c}{P} > \frac{1 + \frac{1}{\alpha\delta}}{\left(1 + \frac{1}{\alpha\delta}\right) + 3 + \alpha\bar{\delta} + \alpha\underline{\delta} + \frac{1}{\alpha\bar{\delta}}}$$

The lower bound on the share of population working at the center amounts to restrictions on $\alpha\bar{\delta}$ and $\alpha\underline{\delta}$ that turn out to be very mild (the proof of the proposition in the Appendix includes a parallel restriction expressed only in terms of the exogenous parameters). To see this, recall that the average employment size of establishments in 1980 was 21.4 at the center and 17.1 at the edge. Therefore, we can conjecture that $\alpha\delta \leq 17.1$ since $\alpha\delta$ represents the smallest establishment size at the edge (the edge also encompasses integrated firms but of size $1 + \alpha\bar{\delta}$). Furthermore, it also follows that $1 + \alpha\bar{\delta} \geq 21.4$ since $1 + \alpha\bar{\delta}$ is the largest establishment size at the center. Note that the restriction set out in Proposition 4 becomes more difficult to meet as $\alpha\bar{\delta}$ falls. Thus, suppose that we very conservatively set $\alpha\delta = 10$ and $\alpha\bar{\delta} = 20.4$. Then Proposition 4 indicates that the share of employment at the center decreases with overall population whenever the share of center employment exceeds 3.2%, a condition that is easily met by all cities in our sample.¹⁷

¹⁷ If one actually uses $\alpha\underline{\delta} = 17.1$ and $\alpha\bar{\delta} = 21.4$, the lower bound required in Proposition 4 becomes even less severe at 2.5%.

To summarize thus far, an increase in overall city population leads to findings for the levels and shares of employment in different areas of the city that are consistent with the data. In particular, population growth leads to an increase in employment levels everywhere, but also to a shift in employment from the center to the edge in shares. These results follow directly from firms having the opportunity to break up their operations geographically.

It is difficult to understand how observed changes in levels and shares of population in different sections of the city could be the result of forces that are not related to an overall expansion in size (i.e., population growth). If other forces were responsible for these changes, and since one needs to introduce scale effects in order to generate cities, reductions in the share of employment at the center will generally lead to reductions in the level of employment as well. Hence, it seems that two elements are needed to obtain models that can reproduce these dimensions of the data. First, one needs models where these changes are the result of city growth. Second, these models should also allow for endogenous employment densities. Evidently, if densities were not endogenous, given that the center county area has not changed in the data, employment at the center would necessarily be predicted to remain constant.

The advantage of writing down a model in which agents' occupations are explicitly considered is that it has predictions for the effect of changes in exogenous variables on the location of different occupations within cities. In Section 2, we presented a set of facts that are related to the locations of agents working in different occupations. Specifically, we showed that the change in the manager to nonmanager ratio was larger at the center than at the edge (Fact 5a). This fact implied that managers are increasingly concentrated at the center relative to the boundary.¹⁸ In addition, Fact 5b showed that the fraction of urban population in management positions increased during the 1980s. Although our model is consistent with this last fact, other forces working at a more aggregate level—such as changing transport and communication costs across cities or between cities and rural areas—may have helped increase the total number of managers in the city beyond that implied by population growth alone (as in Duranton and Puga, 2005). Hence, we first describe the predictions of our model regarding differences in manager to nonmanager ratios between the center and edge that are driven by city population growth (Fact 5a).

The analysis we just carried out suggests that population growth leads to an increase in the number of managers at the center. In fact, it also leads to an increase in the number of managers at the boundary. Some of the new managers establish themselves at the center because of the production externalities generated by managers in that section of the city. Others take advantage of the larger spans of control, as well as lower rents, at the boundary. As we argued earlier, all employees under the supervision of new entrepreneurs at the center work in operation plants located at the periphery. In addition, all new managers at the boundary head integrated firms.

¹⁸ We expressed this fact in terms of differences in ratios between the center and the edge, and not in terms of levels or ratios directly. Since our model focuses on only one city and not a system of cities, it is silent on level differences across cities. In our framework, these cross-sectional differences would in principle stem from different values of L_c , \bar{R} , α , or A across cities.

Because, at the center, the number of managers increases with population whereas the number of workers is fixed, it is clear that the ratio of managers to nonmanagers increases in that area of the city. At the edge, since the number of workers increases in part because of the increase in managers of nonintegrated firms headquartered at the center, this ratio always decreases. Together these results directly lead to Fact 5a. Furthermore, as population increases, all new managers at the center run nonintegrated firms. Given that nonintegrated firms have fewer workers per manager (smaller spans of control), this leads to an increase in the share of city residents that become managers, as in Fact 5b. These results are stated formally in the next proposition, consistent with Fact 5.

PROPOSITION 5. *An increase in population implies an increase in*

- *The difference in the ratio of managers to nonmanagers between the center and the edge, $\frac{E_c}{L_c} - \frac{E_b}{L_b}$.*
- *The number of managers per resident, $\frac{E_c + E_b}{P}$.*

It should be remarked that the model implies a decrease in the ratio of managers to nonmanagers at the edge, which is actually counterfactual. Specifically, the theory overemphasizes the concentration of managers at the center. This implication can be attenuated by requiring that managers rent land at the headquarters' location. This extension, however, would come at the cost of a much more complicated setup. Moreover, we view the increase in manager to nonmanager ratio at the edge as resulting partly from the overall increase in the number of agents in management occupations, as in Fact 5b. An alternative formulation where operating plants also require managers would also lead to a prediction for changes in the edge ratio of managers to nonmanagers consistent with the data.

Our model evidently also has predictions for the number of establishments at the center and at the edge of the city. First, recall that at the center, the number of establishments is equal to the number of managers since establishments at that location are either headquarters or nonintegrated firms, but under our assumptions never just operation plants. It follows immediately that the number of establishments at the center increases with population growth. Furthermore, since new managers at the center operate only nonintegrated firms, the boundary sees an increase in operation plants. The latter two findings are consistent with Fact 6. Because every new manager at the center is associated with an additional operation plant at the edge, and the edge also experiences entry of new integrated firms following population growth, the number of establishments at the edge must increase and, in fact, must increase by more than the increase in center establishments. This implies that the share of establishment at the center must fall, as in Fact 7.

PROPOSITION 6. *An increase in population implies*

- *An increase in the number of establishments located at the center and at the edge, S_c and S_b , with the number of establishments increasing more rapidly at the edge than at the center.*
- *A decrease in the share of establishments at the center, $\frac{S_c}{S_c + S_b}$.*

Finally, we derive the implications of our framework for changes in establishment sizes stemming solely from city population growth. As pointed out earlier, establishments are of three different sizes in our setup: Headquarters of size 1, operation plants of size $\alpha\delta$, and integrated firms of size $1 + \alpha\bar{\delta}$. Hence, the specific combination of firms of each type in a given region of the city determines average establishment size in that region. Since there are no operation plants at the center, firms can only be of size 1 or $1 + \alpha\bar{\delta}$ in that section of the city. As population increases, the number of managers at the center increases and so does the share of establishments of size 1. Therefore, population growth contributes to a decrease in average firm size in the center region, as in Fact 8. In contrast, the boundary comprises only establishments of size $\alpha\delta$ and $1 + \alpha\bar{\delta}$. First, this implies that the average size of establishments is larger at the edge than at the center, unless most firms are production plants and many integrated firms reside at the center. The latter case would make our model consistent with the larger establishment sizes at the center observed in 1980. As population grows, the set of establishments that are production plants increases at the edge, and so does the set of integrated firms. In the next proposition, we show that the increase in the number of production plants dominates, thereby leading to a decrease in firm size at the edge, consistent with Fact 8.

PROPOSITION 7. *An increase in population implies a decrease in the average size of establishments at the city center and edge, $\frac{E_c + L_c}{S_c}$ and $\frac{E_b + L_b}{S_b}$, respectively.*

Thus, our model predicts that population growth reduces establishment sizes in both regions following simple composition effects. The data, however, show that changes in establishment size are negative in both regions for slightly more than half of the cities in our sample. What factors may explain the behavior of establishment size in the remaining cities? Given the theory we have just laid out, a possible answer is that lower communication costs have led to larger spans of control (an increase in α) and, therefore, larger firms throughout the city. The evidence suggests that this phenomenon did not dominate changes in average firm size in most cities in the 1980s, but may nevertheless be significant in more recent time periods for several cities (as argued by Garicano and Rossi-Hansberg, 2006, for the late 1990s).

5. EXTENSIONS

5.1. Labor Mobility. Our analysis to this point has focused on a theory where land rents at the boundary are given by some alternative country-wide nonurban land use. Wages and profits in the city were therefore endogenously determined. In a model of a system of cities, this would be equivalent to assuming a perfectly elastic supply of urban land at \bar{R} and high moving costs that impede the mobility of workers between cities. One might instead imagine an alternative construct where wages are fixed at some economy-wide level, w , exogenous to the city. Heterogeneity in the quality of land in different regions would then attract a certain population that in turn would determine all land prices in the city. This section establishes that all propositions derived in the previous sections continue to hold using this alternative interpretation, provided a mild restriction on parameters.

The model remains as in Section 4, except that condition (20) now determines land rents at the edge instead of wages,

$$\bar{R} = \frac{AP - AL_c \left(1 - \frac{\delta}{\bar{\delta}}\right) - w \left(4 + \alpha \underline{\delta} + \alpha \bar{\delta} + \frac{1}{\alpha \underline{\delta}} + \frac{1}{\alpha \bar{\delta}}\right)}{2 + \alpha \underline{\delta} + \alpha \bar{\delta}}.$$

It is straightforward to check that $\partial \bar{R} / \partial P > 0$, $\partial \bar{R} / \partial L_c < 0$, and $\partial \bar{R} / \partial w < 0$, consistent with Proposition 2. We can then prove that results replicating Propositions 3–7 continue to hold. The derivations for a subset of these results require that the number of managers per establishment at the boundary be greater than one half, $E_b/S_b > 1/2$.¹⁹ Figure 9(b) suggests that this is likely the case in the data, where a given percentage change in the number of establishments is associated with approximately twice that percentage change in the number of managers. These results are formalized in the next proposition.

PROPOSITION 8. *With exogenous wages, w , and endogenous land rents at the edge, \bar{R} , an increase in population implies*

- *An increase in total employment at the center, $E_c + L_c$, and at the edge, $E_b + L_b$.*
- *A decrease in the employment share at the center, $\frac{E_c+L_c}{P}$.*
- *An increase in (a) the difference in the ratio of managers to nonmanagers between the center and the edge, $\frac{E_c}{L_c} - \frac{E_b}{L_b}$ if $\frac{E_b}{S_b} > \frac{1}{2}$, and (b) the number of managers per resident, $\frac{E_c+E_b}{P}$.*
- *An increase in the number of establishments located at the center and at the edge, S_c and S_b , respectively, and a decrease in the share of establishments at the center, $\frac{S_c}{S_c+S_b}$.*
- *A decrease in the average size of establishments located at the center and at the edge, $\frac{E_c+L_c}{S_c}$ and $\frac{E_b+L_b}{S_b}$, respectively, if $\frac{E_b}{S_b} > \frac{1}{2}$.*

5.2. Changes in Communication Technology. In a model that allows for firm fragmentation, we have shown that changes in the internal structure of cities associated with population growth are consistent with the nine facts documented in Section 2. Of course, the model is only consistent with these facts, and other changes in the economic environment, technology or preferences, might also yield the nine observations we are trying to account for. One important candidate relates to changes in communication technology, which in our model is represented by α . An improvement in communications leads to an increase in spans of control in both integrated and fragmented firms. There is a long literature that argues for the importance of changes in information and communication technology and, in particular, Duranton and Puga (2005) argue that these changes have led to a switch from sectoral to functional specialization across cities. Although Duranton and Puga (2005) do not claim that changes in communication technology have led

¹⁹ However, since a different price is now taken as given from the city’s standpoint, the restriction on the share of center population in Section 3, Proposition 4, is no longer necessary.

to changes in the internal structure of cities, it is interesting to explore whether, in our theory, changes in α can lead to the observations in Section 2. In fact, the next proposition shows that increases in α are inconsistent with important observations on changes in urban form.

As α increases, the size of firms rises, which implies that fewer agents become managers. This reduction in the number of managers induces fewer spillovers at the center, since spillovers depend on the number of managers in each location and managers are mostly located in city centers. It follows that total population decreases at the center and increases at the edge. At the same time, however, as α increases, it is clear that the ratio of managers per worker must fall. The latter implication is noticeably counterfactual, as the number of managers per resident increased in every city in our sample, as discussed in Section 2.3. In addition, this basic counterfactual implication is associated with several other counterfactual findings induced by improving communication technology at the individual city level. In particular, population falls at the center, and so does the number of establishments whereas establishment size increases. In sum, our theory suggests that any changes in α that have occurred must be dominated by increases in population in order for them to be consistent with facts at the city level.

PROPOSITION 9. *In the original setup with exogenous land rents at the edge, \bar{R} , and endogenous wage, w , an improvement in communication technology, α , implies*

- *A decrease in the wage, w .*
- *A decrease in the number of managers at the center, E_c , and a decrease in total population at the center, $E_c + L_c$.*
- *A decrease in the number of managers at the boundary, E_b , and an increase in the the total population at the edge, $E_b + L_b$.*
- *A decrease in the share of population at the center.*
- *A decrease in the ratio of managers per resident, $(E_c + E_b)/P$.*
- *A decrease in the number of establishments at the center, and an ambiguous effect in the number of establishments at the edge or the share of establishments at the center.*
- *An increase in the average size of establishments at the center, and an ambiguous effect on establishment size at the edge.*

6. CHANGES IN CITY STRUCTURE AND POPULATION GROWTH

In Section 2, we presented a set of stylized facts on the evolution of city structure. We then argued in the three subsequent sections that observed increases in population alone could help rationalize those facts. At this stage, therefore, it is natural to ask whether one could establish the implications of our model more directly in the data. As a first pass, we can use the data to assess whether the changes in city structure presented in Facts 2–9 are in fact correlated with population growth. However, one needs to be cautious in the interpretation of such an empirical exercise. First, the theory predicts that the effect of changes in population size should lead to Facts 2–9 only if cross-sectional characteristics of cities are properly controlled for. In particular, the theory has predictions for

TABLE 1
CORRELATIONS WITH POPULATION GROWTH

Variable	Correlation
Center Population Growth	0.511
Edge Population Growth	0.558
Center Employment Growth	0.496
Edge Employment Growth	0.538
Change in Edge Population Share	0.127
Change in Edge Employment Share	0.155
Change in Management - Nonmanagement Shares	0.133
Change in Management over Nonmanagement Ratio	0.128
Change in Center Establishments	0.381
Change in Edge Establishments	0.572
Change in Center Establishment Share	-0.188
Change in Center Establishment Size	0.467
Change in Edge Establishment Size	0.129

the sign of these correlations after controlling for center county land sizes (L_c), land rents at the boundary (\bar{R}), spans of control (α , δ , and δ), and productivity (A), as well as any changes in these variables during the 1980s. At this point, we do not have residential land rents at the boundary for 1980 or a suitable proxy. However, we can control for land area L_c and, to some degree, for productivity as well as spans of control using the 1980 level of per capita income and ratio of managers to population respectively. Since our theory also abstracts from available city infrastructure and other idiosyncratic city characteristics, we take city age into consideration by using the decade in which the city became one of the largest 50 cities in the United States. This last variable helps but cannot obviously capture all cross-sectional characteristics omitted from the model. Because of the size of our sample, we do not control for changes in any of these variables. Finally, a key problem with calculating simple correlations is that our theory does not predict a linear response of city structure to population changes.²⁰ Despite these caveats regarding the mapping between these correlations and our theoretical results, Table 1 presents encouraging results that are consistent with the framework introduced in this paper.

Table 1 presents correlations between population growth and the residuals obtained from running an OLS regression of the various changes in city structure laid out in Section 2 against the controls discussed above. Observe that all but the last two correlations, the ones related to establishment size, have the sign predicted by our theory. Some of these correlations are admittedly low. Nevertheless, our framework does surprisingly well given that increases in only one independent

²⁰ In particular, one might focus on the subset of cities with negative population growth. Of the MSAs ranked 50–100, however, only 3 additional cities with population greater than 400,000 experienced negative growth between 1980 and 1990. Beyond these MSAs, cities become small enough that, for the small fraction that declined over the 1980–90 period, the distinction between center and edge counties ceases to be meaningful.

variable, namely population growth, are shown to be consistent with 11 diverse changes in the internal structure of cities.²¹ The incorrect sign on the correlation between center/edge establishment sizes and population growth is somewhat disappointing, and indeed the model does not contain a force that would lead to larger firms in larger cities. Here, firms are larger only if they decide to integrate but there are no differences across integrated firms. In practice, larger cities have larger firms partly because demand for firms' varieties is larger, a dimension from which we have abstracted. Changes in information technology that have led to larger spans of control could also help account for these correlations.

7. CONCLUSIONS

This article makes three distinct contributions. First we document a set of facts regarding changes in urban structure experienced by U.S. cities in the 1980s. These facts include overall population growth; an increase in residents and employment at the center and city boundaries; a reduction in the share of employment and residents in the center region of cities; a concentration of managers relative to nonmanagers at the center; an increase in establishments in both areas of the city but a decrease in establishment shares at the center; and a decline in establishment size both at the center and at the edge of cities. Second, we propose a theory that incorporates firms' location and integration decisions and characterize the implications of such a theory for urban structure. Third, we show that population growth alone is consistent with the set of changes observed in the 1980s, thereby highlighting the effects of population growth on urban structure, through firm fragmentation.

The theory we present has urban policy implications that differ from more standard models of urban structure. In particular, we provide a framework that could potentially be used to analyze the kinds of policies aimed at "reviving city centers" that have been put in practice in many cities across the United States. Given that our framework includes agglomeration forces in the form of externalities, some urban policies may improve equilibrium allocations in our setup. However, the specific type of policy in place is critical. For example, Au and Henderson (2005) show that restrictions on urban migration have had important efficiency costs in China. For now, the question of whether zoning restrictions or location subsidies, as in Rossi-Hansberg (2004), are optimal in our setup, and in general the design of these policies, is left to future research.

In order to underscore the importance of firms' location decisions, as well as their decision regarding whether or not to integrate their operations, our model abstracts from important elements of cities typically emphasized in the urban literature. One such element is a spatial setup in which multiple subcenters may arise (see Fujita and Ogawa, 1982; Lucas and Rossi-Hansberg, 2002). Other dimensions, such as the effect of durable housing structures, as in Glaeser and Gyourko

²¹ If we eliminate from the sample the four fastest growing cities (Orlando, Las Vegas, Austin, and Phoenix), correlations related to occupations increase substantially (both become larger than 0.22). This result only reinforces the notion of nonlinear responses to population growth in our model.

(2005), and urbanization patterns in a system of cities, as in Henderson (2005), and Henderson and Wang (2004), are undoubtedly important. In addition, our theory focuses on one particular type of agglomeration force. However, as argued by Rosenthal and Strange (2003), different agglomeration forces interact in metropolitan areas. One could, in principle, study any of these forces along with the firm’s location and integration decisions we emphasize. The explanatory power gained by incorporating these firms’ decisions with respect to the facts we document in this article will, we hope, push the urban literature to add these margins to the rich set of frameworks available.

APPENDIX

PROOF OF PROPOSITION 1. The proof proceeds by contradiction. Suppose that both integrated and nonintegrated firms exist in both areas of the city. Then by (2), it must be the case that

$$(A.1) \quad F_{bb} = F_{cc} = F_{cb} = F_{bc}.$$

The fact that $F_{cc} = F_{bb}$ implies that

$$(A.2) \quad \begin{aligned} (AE_c - w - R_c)\alpha\bar{\delta} &= (AE_b - w - \bar{R})\alpha\bar{\delta} \text{ or} \\ AE_c - AE_b &= R_c - \bar{R}. \end{aligned}$$

Similarly, the fact that $F_{cb} = F_{bc}$ implies that

$$(A.3) \quad \begin{aligned} (AE_c - w - \bar{R})\alpha\delta &= (AE_b - w - R_c)\alpha\delta \text{ or} \\ AE_c - AE_b &= \bar{R} - R_c. \end{aligned}$$

Equations (A.2) and (A.3) can only hold if $R_c = \bar{R} = R$, in which case $E_c = E_b = E$. It follows that profits for an integrated firm are $(AE - w - R)\alpha\bar{\delta}$ whereas those of a nonintegrated firm are $(AE - w - R)\alpha\delta$. That is, $F_{cc} = F_{bb} > F_{cb} = F_{bc}$ which contradicts (A.1). ■

PROOF OF PROPOSITION 2. Simple partial derivatives imply that

$$\begin{aligned} \frac{\partial w}{\partial P} &= \frac{A}{D} > 0, & \frac{\partial w}{\partial A} &= \frac{P - L_c \left(1 - \frac{\delta}{\bar{\delta}}\right)}{D} > 0, \\ \frac{\partial w}{\partial L_c} &= -\frac{A}{D} \left(1 - \frac{\delta}{\bar{\delta}}\right) < 0, & \frac{\partial w}{\partial \bar{R}} &= \frac{-(2 + \alpha\delta + \alpha\bar{\delta})}{D} < 0, \end{aligned}$$

and

$$\frac{\partial w}{\partial \alpha} = -\frac{(\delta + \bar{\delta})}{D^2} - w \frac{\delta + \bar{\delta} - \frac{1}{\alpha^2\delta} - \frac{1}{\alpha^2\bar{\delta}}}{D^2} < 0.$$

The sign of the last term is guaranteed since the span of control of integrated and nonintegrated firms is greater than $\alpha\bar{\delta} > \alpha\underline{\delta} > 1$. ■

PROOF OF PROPOSITION 3. Employment in the center of the city is given by

$$E_c + L_c = \frac{1 + \frac{1}{\alpha\underline{\delta}}}{A}w + \frac{\bar{R}}{A} + L_c.$$

Differentiating with respect to P , we obtain

$$\frac{\partial(E_c + L_c)}{\partial P} = \frac{1 + \frac{1}{\alpha\underline{\delta}}}{D} \frac{\partial w}{\partial P} > 0,$$

which captures the increase in population at the center.

Total employment at the edge is given by

$$\begin{aligned} E_b + L_b &= \left(E_c - \frac{L_c}{\alpha\bar{\delta}}\right)\alpha\underline{\delta} + E_b(1 + \alpha\bar{\delta}) \\ &= \frac{\bar{R}}{A}(1 + \alpha\underline{\delta} + \alpha\bar{\delta}) - L_c\frac{\underline{\delta}}{\bar{\delta}} + \frac{3 + \alpha\underline{\delta} + \alpha\bar{\delta} + \frac{1}{\alpha\bar{\delta}}}{A}w \end{aligned}$$

so that

$$\frac{\partial(E_b + L_b)}{\partial P} = \frac{3 + \alpha\underline{\delta} + \alpha\bar{\delta} + \frac{1}{\alpha\bar{\delta}}}{D} > 0,$$

which yields the increase in population at the boundary. ■

PROOF OF PROPOSITION 4. The employment share at the center is given by

$$\frac{E_c + L_c}{P} = \left(\frac{1 + \frac{1}{\alpha\underline{\delta}}}{A}w + \frac{\bar{R}}{A} + L_c \right) \frac{1}{P}.$$

Hence, the derivative with respect to population is

$$\frac{\partial \frac{E_c + L_c}{P}}{\partial P} = \frac{P \frac{\partial E_c}{\partial P} - (E_c + L_c)}{P^2},$$

where

$$\frac{\partial E_c}{\partial P} = \frac{1 + \frac{1}{\alpha \underline{\delta}}}{D}.$$

It follows that $\frac{\partial \frac{E_c + L_c}{P}}{\partial P} < 0$ if and only if

$$\frac{\partial E_c}{\partial P} < \frac{E_c + L_c}{P},$$

or, alternatively,

$$\frac{E_c + L_c}{P} > \frac{1 + \frac{1}{\alpha \underline{\delta}}}{\left(1 + \frac{1}{\alpha \underline{\delta}}\right) + 3 + \alpha \bar{\delta} + \alpha \underline{\delta} + \frac{1}{\alpha \bar{\delta}}}.$$

This last condition can be rewritten in terms of exogenous parameters only,

$$\left(3 + \alpha \underline{\delta} + \alpha \bar{\delta} + \frac{2}{\alpha \bar{\delta}} + \frac{\delta}{\bar{\delta}}\right) L_c > \bar{R} \left(\frac{\bar{\delta}}{\underline{\delta}} - 1 + \frac{1}{\alpha \underline{\delta}} - \frac{1}{\alpha \bar{\delta}}\right),$$

in which case the share of employment at the center decreases with population growth. ■

PROOF OF PROPOSITION 5.

(i) $\frac{E_c}{L_c} - \frac{E_b}{L_b}$ increases with P .

We analyze each term in turn. Since L_c is fixed and E_c increases with P , $\frac{E_c}{L_c}$ clearly increases with P ,

$$\frac{\partial \frac{E_c}{L_c}}{\partial P} = \frac{1 + \frac{1}{\alpha \underline{\delta}}}{L_c D} > 0.$$

To analyze the second term, note that E_b/L_b is given by

$$\begin{aligned} \frac{E_b}{L_b} &= \frac{E_b}{\left(E_c - \frac{L_c}{\alpha \bar{\delta}}\right) \alpha \underline{\delta} + E_b \alpha \bar{\delta}} \\ &> \frac{\left(1 + \frac{1}{\alpha \bar{\delta}}\right) w + \bar{R}}{\left(2 + \alpha \bar{\delta} + \alpha \underline{\delta}\right) w + \alpha (\underline{\delta} + \bar{\delta}) \bar{R}}. \end{aligned}$$

Hence,

$$\begin{aligned} \frac{\partial \frac{E_b}{L_b}}{\partial P} &= \frac{1}{DL_b} \left(1 + \frac{1}{\alpha \bar{\delta}} - \frac{E_b}{L_b} (2 + \alpha \underline{\delta} + \alpha \bar{\delta}) \right) \\ &< \frac{1}{DL_b} \left(1 - \frac{\bar{\delta}(2 + \alpha \underline{\delta} + \alpha \bar{\delta})w + \bar{R}(\bar{\delta} - \underline{\delta} + \alpha \bar{\delta} \underline{\delta} + \alpha \bar{\delta}^2)}{\bar{\delta}[(2 + \alpha \bar{\delta} + \alpha \underline{\delta})w + \alpha(\bar{\delta} + \underline{\delta})\bar{R}]} \right) < 0, \end{aligned}$$

from which it immediately follows that that $\frac{\partial(\frac{E_c}{L_c} - \frac{E_b}{L_b})}{\partial P} > 0$.

(ii) $\frac{(E_c + E_b)}{P}$ increases with P .

To see this, observe that

$$\frac{E_c}{P} = \left(1 + \frac{1}{\frac{\alpha \underline{\delta}}{A} w + \frac{\bar{R}}{A}} \right) \frac{1}{P}.$$

Hence, the derivative with respect to population is

$$\begin{aligned} \frac{E_c}{P} &= \frac{1 + \frac{1}{\alpha \underline{\delta}}}{D} \left(1 - \frac{L_c}{P} \left(1 - \frac{\delta}{\bar{\delta}} \right) \right) + \left(1 - \frac{1 + \frac{1}{\alpha \underline{\delta}}}{D} (2 + \alpha \underline{\delta} + \alpha \bar{\delta}) \right) \frac{\bar{R}}{AP} \\ \frac{\partial \frac{E_c}{P}}{\partial P} &= \frac{1}{P^2} \left(\frac{1 + \frac{1}{\alpha \underline{\delta}}}{D} L_c \left(1 - \frac{\delta}{\bar{\delta}} \right) - \left(1 - \frac{1 + \frac{1}{\alpha \underline{\delta}}}{D} (2 + \alpha \underline{\delta} + \alpha \bar{\delta}) \right) \frac{\bar{R}}{A} \right) \\ &= \frac{1}{P^2} \left(\frac{1 + \frac{1}{\alpha \underline{\delta}}}{D} L_c \left(1 - \frac{\delta}{\bar{\delta}} \right) \right. \\ &\quad \left. + \left(\frac{3 + \alpha \underline{\delta} + \alpha \bar{\delta} + \frac{2}{\alpha \underline{\delta}} + \frac{\bar{\delta}}{\underline{\delta}}}{4 + \alpha \underline{\delta} + \alpha \bar{\delta} + \frac{1}{\alpha \underline{\delta}} + \frac{1}{\alpha \bar{\delta}}} - 1 \right) \frac{\bar{R}}{A} \right) > 0, \end{aligned}$$

where the inequality follows from $\bar{\delta} > \delta$. Moreover, note that

$$\begin{aligned} \frac{E_b}{P} &= \frac{1 + \frac{1}{\alpha\bar{\delta}}}{PA} w + \frac{\bar{R}}{PA} \\ &= \frac{1 + \frac{1}{\alpha\bar{\delta}}}{D} \left(1 - \frac{L_c}{P} \left(1 - \frac{\delta}{\bar{\delta}} \right) - (2 + \alpha\underline{\delta} + \alpha\bar{\delta}) \frac{\bar{R}}{PA} \right) + \frac{\bar{R}}{PA}. \end{aligned}$$

Hence,

$$\begin{aligned} \frac{\partial \frac{E_b}{P}}{\partial P} &= \frac{1}{P^2} \left(\frac{\left(1 + \frac{1}{\alpha\bar{\delta}} \right) \left(1 - \frac{\delta}{\bar{\delta}} \right)}{D} L_c \right. \\ &\quad \left. + \left(\frac{3 + \alpha\underline{\delta} + \alpha\bar{\delta} + \frac{2}{\alpha\bar{\delta}} + \frac{\delta}{\bar{\delta}}}{4 + \alpha\underline{\delta} + \alpha\bar{\delta} + \frac{1}{\alpha\underline{\delta}} + \frac{1}{\alpha\bar{\delta}}} - 1 \right) \frac{\bar{R}}{A} \right), \end{aligned}$$

so that

$$\begin{aligned} \frac{\partial \frac{E_c + E_b}{P}}{\partial P} &= \frac{\left(2 + \frac{1}{\alpha\underline{\delta}} + \frac{1}{\alpha\bar{\delta}} \right) \left(1 - \frac{\delta}{\bar{\delta}} \right)}{P^2 D} L_c \\ &\quad + \left(\frac{6 + 2\alpha\underline{\delta} + 2\alpha\bar{\delta} + \frac{2}{\alpha\underline{\delta}} + \frac{2}{\alpha\bar{\delta}} + \left(\frac{\bar{\delta}}{\underline{\delta}} + \frac{\delta}{\bar{\delta}} \right)}{4 + \alpha\underline{\delta} + \alpha\bar{\delta} + \frac{1}{\alpha\underline{\delta}} + \frac{1}{\alpha\bar{\delta}}} - 2 \right) \frac{\bar{R}}{P^2 A}, \end{aligned}$$

which is positive if

$$\frac{\bar{\delta}}{\underline{\delta}} + \frac{\delta}{\bar{\delta}} > 2$$

or if

$$\bar{\delta}^2 - 2\bar{\delta}\underline{\delta} + \underline{\delta}^2 = (\bar{\delta} - \underline{\delta})^2 > 0,$$

which holds trivially. ■

PROOF OF PROPOSITION 6. The total number of establishments at the center is given by

$$S_c = E_c + E_{bc} = E_c = \frac{1 + \frac{1}{\alpha\bar{\delta}}}{A} w + \frac{\bar{R}}{A}.$$

It follows that

$$\frac{\partial S_c}{\partial P} = \frac{1 + \frac{1}{\alpha \underline{\delta}}}{D} > 0,$$

which depicts the rise in establishments at the center. The number of establishments at the edge is given by

$$\begin{aligned} S_b &= E_b + E_{cb} = E_b + E_c - E_{cc} \\ &= \frac{2 + \frac{1}{\alpha \underline{\delta}} + \frac{1}{\alpha \bar{\delta}}}{A} w + 2 \frac{\bar{R}}{A} - \frac{L_c}{\alpha \bar{\delta}}. \end{aligned}$$

Therefore

$$\begin{aligned} \frac{\partial S_b}{\partial P} &= \frac{2 + \frac{1}{\alpha \underline{\delta}} + \frac{1}{\alpha \bar{\delta}}}{A} \frac{\partial w}{\partial P} \\ &= \frac{2 + \frac{1}{\alpha \underline{\delta}} + \frac{1}{\alpha \bar{\delta}}}{D} > 0, \end{aligned}$$

which establishes the increase in establishments at the edge. It is also the case that

$$\frac{\partial S_c}{\partial P} = \frac{1 + \frac{1}{\alpha \underline{\delta}}}{D} < \frac{2 + \frac{1}{\alpha \underline{\delta}} + \frac{1}{\alpha \bar{\delta}}}{D} = \frac{\partial S_b}{\partial P},$$

so that the increase in the number of establishments is greater at the edge than at the center.

Finally, the change in the share of establishments with respect to population is given by

$$\begin{aligned} \frac{\partial \frac{S_c}{S_c + S_b}}{\partial P} &= \frac{(S_c + S_b) \left(\frac{1 + \frac{1}{\alpha \underline{\delta}}}{A} \right) \frac{\partial w}{\partial P} - S_c \frac{1}{A} \left[3 + \frac{1}{\alpha \bar{\delta}} + \frac{2}{\alpha \underline{\delta}} \right] \frac{\partial w}{\partial P}}{(S_c + S_b)^2} \\ &= \frac{\frac{1}{A} \frac{\partial w}{\partial P} \left[-S_c \left(2 + \frac{1}{\alpha \underline{\delta}} + \frac{1}{\alpha \bar{\delta}} \right) + S_b \left(1 + \frac{1}{\alpha \underline{\delta}} \right) \right]}{(S_c + S_b)^2}. \end{aligned}$$

The above expression is negative whenever

$$\begin{aligned}
 S_b &< S_c \frac{\left(1 + \frac{1}{\alpha\delta} + 1 + \frac{1}{\alpha\bar{\delta}}\right)}{\left(1 + \frac{1}{\alpha\delta}\right)} \\
 &= S_c \left(1 + \frac{1 + \frac{1}{\alpha\bar{\delta}}}{1 + \frac{1}{\alpha\delta}}\right) < 2S_c.
 \end{aligned}$$

Thus, $S_c > \frac{1}{2}S_b$ whenever

$$\frac{S_c}{S_c + S_b} > \frac{1}{3}.$$

This restriction, however, is always satisfied since

$$\frac{S_c}{S_c + S_b} = \frac{\left(\frac{1 + \frac{1}{\alpha\bar{\delta}}}{A}\right)w + \frac{\bar{R}}{A}}{\frac{1}{A}\left[3 + \frac{1}{\alpha\delta} + \frac{2}{\alpha\bar{\delta}}\right]w + 3\frac{\bar{R}}{A} - \frac{L_c}{\alpha\bar{\delta}}} > \frac{1}{3}$$

holds when

$$\frac{L_c}{\alpha\bar{\delta}} > \frac{w}{A} \left(\frac{1}{\alpha\bar{\delta}} - \frac{1}{\alpha\delta}\right),$$

which is always the case since $\frac{1}{\alpha\bar{\delta}} - \frac{1}{\alpha\delta} < 0$. ■

PROOF OF PROPOSITION 7. Average establishment size at the center is given by

$$\frac{L_c + E_c}{S_c} = \frac{L_c + E_c}{E_c} = \frac{L_c + \frac{1 + \frac{1}{\alpha\bar{\delta}}}{A}w + \frac{\bar{R}}{A}}{\frac{1 + \frac{1}{\alpha\bar{\delta}}}{A}w + \frac{\bar{R}}{A}},$$

so that

$$\frac{\partial \frac{L_c + E_c}{E_c}}{\partial P} = -\frac{\partial E_c}{\partial P} \frac{L_c}{(E_c)^2} = -\frac{1 + \frac{1}{\alpha \underline{\delta}}}{D} \frac{L_c}{(E_c)^2} < 0.$$

Hence, average firm size at the center decreases with population growth. Average establishment size at the edge is analogously given by

$$\frac{E_b + L_b}{S_b} = \frac{\bar{R}(1 + \alpha \underline{\delta} + \alpha \bar{\delta}) - AL_c \frac{\delta}{\bar{\delta}} + \left(3 + \alpha \underline{\delta} + \alpha \bar{\delta} + \frac{1}{\alpha \bar{\delta}}\right) w}{\left(2 + \frac{1}{\alpha \underline{\delta}} + \frac{1}{\alpha \bar{\delta}}\right) w + 2\bar{R} - A \frac{L_c}{\alpha \bar{\delta}}}.$$

It follows that

$$\frac{\partial \frac{E_b + L_b}{S_b}}{\partial P} = \frac{1}{S_b} \frac{A}{D} \left(\left(3 + \alpha \underline{\delta} + \alpha \bar{\delta} + \frac{1}{\alpha \bar{\delta}}\right) - \frac{E_b + L_b}{S_b} \left(2 + \frac{1}{\alpha \underline{\delta}} + \frac{1}{\alpha \bar{\delta}}\right) \right) < 0$$

when

$$\frac{3 + \alpha \underline{\delta} + \alpha \bar{\delta} + \frac{1}{\alpha \bar{\delta}}}{2 + \frac{1}{\alpha \underline{\delta}} + \frac{1}{\alpha \bar{\delta}}} < \frac{E_b + L_b}{S_b},$$

or

$$\frac{AL_c}{\bar{\delta}\alpha} > -\left(\frac{\bar{\delta} - \underline{\delta} + \alpha(\bar{\delta} - \underline{\delta})^2}{1 + \bar{\delta}^2\alpha^2 - \underline{\delta}\bar{\delta}\alpha^2 + 2\bar{\delta}\alpha - \underline{\delta}\alpha}\right) \frac{\bar{R}}{\bar{\delta}},$$

which always holds since $1 + \bar{\delta}^2\alpha^2 - \underline{\delta}\bar{\delta}\alpha^2 + 2\bar{\delta}\alpha - \underline{\delta}\alpha > 0$. Consequently, average firm size at the edge also falls. \blacksquare

PROOF OF PROPOSITION 8.

(i) At the center, we have

$$\frac{\partial(E_c + L_c)}{\partial P} = \frac{1}{A} \frac{\partial \bar{R}}{\partial P} = \frac{1}{D'} > 0,$$

where $D' = 2 + \alpha \underline{\delta} + \alpha \bar{\delta}$. With respect to the edge, we have

$$E_b + L_b = (1 + \alpha \bar{\delta}) E_b + \alpha \underline{\delta} E_c - \alpha \underline{\delta} E_{cc}.$$

Therefore,

$$\frac{\partial(E_b + L_b)}{\partial P} = (1 + \alpha\bar{\delta}) \frac{\partial E_b}{\partial P} + \alpha\underline{\delta} \frac{\partial E_c}{\partial P} = \frac{1}{D'} (1 + \alpha\bar{\delta} + \alpha\underline{\delta}) > 0$$

(ii) Taking the derivative of $\frac{E_c + L_c}{P}$ with respect to P yields

$$\begin{aligned} \frac{\partial \frac{E_c + L_c}{P}}{\partial P} &= -\frac{1}{AP^2} \left(\left(1 + \frac{1}{\alpha\underline{\delta}}\right) w + \bar{R} + AL_c \right) + \frac{1}{PD'} \\ &= -\frac{1}{P} \left[\frac{\left(\left(1 + \frac{1}{\alpha\underline{\delta}}\right) w + \bar{R} + AL_c \right) D' - AP}{APD'} \right], \end{aligned}$$

which is strictly negative when

$$\left(\left(1 + \frac{1}{\alpha\underline{\delta}}\right) w + \bar{R} + AL_c \right) D' - AP > 0.$$

The latter condition holds if and only if

$$\begin{aligned} w \left[\left(1 + \frac{1}{\alpha\underline{\delta}}\right) D' - \left(4 + \alpha\underline{\delta} + \alpha\bar{\delta} + \frac{1}{\alpha\underline{\delta}} + \frac{1}{\alpha\bar{\delta}}\right) \right] \\ + AL_c \left[D' - \left(1 - \frac{\delta}{\bar{\delta}}\right) \right] > 0, \end{aligned}$$

or, alternatively, if

$$\left(1 + \frac{1}{\alpha\underline{\delta}}\right) D' > 4 + \alpha\underline{\delta} + \alpha\bar{\delta} + \frac{1}{\alpha\underline{\delta}} + \frac{1}{\alpha\bar{\delta}}$$

and

$$D' > \left(1 - \frac{\delta}{\bar{\delta}}\right),$$

which both hold since $\bar{\delta} > \underline{\delta}$.

(iii) (a) $E_c/L_c - E_b/L_b$ increases in P .

We have that

$$\frac{\partial \left(\frac{E_c}{L_c} - \frac{E_b}{L_b} \right)}{\partial P} = \frac{1}{L_c} \frac{\partial E_c}{\partial P} - \frac{1}{L_b^2} \left(\frac{\partial E_b}{\partial P} L_b - \frac{\partial L_b}{\partial P} E_b \right).$$

But since $\partial E_c/\partial P > 0$, it is sufficient to show that

$$(A.4) \quad \frac{\partial E_b}{\partial P} L_b - \frac{\partial L_b}{\partial P} E_b < 0.$$

Note that $L_b = (E_c - E_{cc})\alpha\bar{\delta} + E_b\alpha\bar{\delta}$ so that $\partial L_b/\partial P = \alpha\bar{\delta}\partial E_c/\partial P + \alpha\bar{\delta}\partial E_b/\partial P$. Then the LHS of (A.4) becomes

$$\begin{aligned} & \frac{\partial E_b}{\partial P} (\alpha\bar{\delta}E_c - \alpha\bar{\delta}E_{cc} + \alpha\bar{\delta}E_b) - E_b \left(\alpha\bar{\delta}\frac{\partial E_c}{\partial P} + \alpha\bar{\delta}\frac{\partial E_b}{\partial P} \right) \\ &= \alpha\bar{\delta} \left(\frac{\partial E_b}{\partial P} E_c - \frac{\partial E_b}{\partial P} E_{cc} - \frac{\partial E_c}{\partial P} E_b \right) \\ &= \frac{\alpha\bar{\delta}}{D'} (E_c - E_{cc} - E_b) \end{aligned}$$

since $\partial E_c/\partial P = \partial E_b/\partial P = 1/D' > 0$. It then follows that (A.4) holds if $E_c - E_{cc} - E_b < 0$, or, equivalently, $E_{cb} < E_b$, which holds whenever

$$\frac{E_b}{S_b} > \frac{1}{2},$$

since $S_b - E_b = E_{cb}$.

- (b) $\frac{E_c + E_b}{P}$ increases with P .

$$\frac{E_c + E_b}{P} = \frac{1}{AP} \left(\left(2 + \frac{1}{\alpha\bar{\delta}} + \frac{1}{\alpha\bar{\delta}} \right) w + 2\bar{R} \right).$$

Thus,

$$\begin{aligned} \frac{\partial \frac{E_c + E_b}{P}}{\partial P} &= \frac{2}{PD'} - \frac{1}{AP^2} \left(\left(2 + \frac{1}{\alpha\bar{\delta}} + \frac{1}{\alpha\bar{\delta}} \right) w + 2\bar{R} \right) \\ &= \frac{1}{P} \left(\frac{2}{2 + \alpha\bar{\delta} + \alpha\bar{\delta}} - \frac{E_c + E_b}{P} \right). \end{aligned}$$

If more than half of the firms in the economy are integrated, $(E_c + E_b)/P < 1/(1 + \alpha\bar{\delta}/2 + \alpha\bar{\delta}/2)$. Hence the above expression is positive if

$$\frac{2}{2 + \alpha\bar{\delta} + \alpha\bar{\delta}} \geq \frac{1}{1 + \alpha\bar{\delta}/2 + \alpha\bar{\delta}/2},$$

which is trivially satisfied with equality. Observe also that when $E_b/S_b > 1/2$, and since $E_c = S_c$, then

$$E_b > \frac{1}{2}S_b \Leftrightarrow E_b + E_c > \frac{1}{2}(S_b + S_c) + \frac{1}{2}S_c$$

so that

$$\frac{E_b + E_c}{S_b + S_c} > \frac{1}{2} + \frac{1}{2} \frac{S_c}{S_b + S_c} > \frac{1}{2}.$$

- (iv) The total number of establishments at the center is given by $S_c = E_c + E_{bc} = E_c$. Thus, we have

$$(A.5) \quad S_c = \frac{1 + \frac{1}{\alpha\delta}}{A} w + \frac{\bar{R}}{A}.$$

Similarly, the total number of establishments at the edge is

$$(A.6) \quad S_b = E_b + E_{cb} = \frac{1}{A} \left[2 + \frac{1}{\alpha\delta} + \frac{1}{\alpha\delta} \right] w + \frac{2}{A} \bar{R} - \frac{L_c}{\alpha\delta}.$$

It follows that

$$\frac{\partial S_c}{\partial P} = \frac{\partial}{\partial P} \left(\frac{\bar{R}}{A} \right) = \frac{1}{D'} > 0$$

and

$$\frac{\partial S_b}{\partial P} = \frac{\partial}{\partial P} \left(\frac{2}{A} \bar{R} \right) = \frac{2}{D'} > 0,$$

which also implies that $\partial S_b / \partial P > \partial S_c / \partial P$. To show that the share of establishments in the center declines with population, observe that

$$\frac{\partial \frac{S_c}{S_c + S_b}}{\partial P} = \frac{\frac{\partial \bar{R}}{\partial P} (S_c + S_b) - 3 \frac{\partial \bar{R}}{\partial P} S_c}{A(S_c + S_b)^2} = \frac{S_c + S_b - 3S_c}{D' (S_c + S_b)^2} < 0$$

when

$$\frac{S_c}{S_c + S_b} > \frac{1}{3},$$

which is always the case as shown in Proposition 6.

- (v) The average size of establishment at the center is given by

$$\frac{E_c + L_c}{S_c} = 1 + \frac{L_c}{E_c}.$$

Therefore,

$$\frac{\partial \left(1 + \frac{L_c}{E_c}\right)}{\partial P} = - \left(\frac{L_c/D'}{E_c^2}\right) < 0.$$

The average size of establishment at the edge is given by

$$\frac{E_b + L_b}{S_b} = \frac{(1 + \alpha\bar{\delta})E_b + \alpha\underline{\delta}E_{cb}}{E_b + E_{cb}}.$$

Differentiating with respect to P yields

$$\begin{aligned} \frac{\partial \frac{E_b + L_b}{S_b}}{\partial P} &= \frac{\left((1 + \alpha\bar{\delta})\frac{\partial E_b}{\partial P} + \alpha\underline{\delta}\frac{\partial E_{cb}}{\partial P}\right)(E_b + E_{cb})}{S_b^2} \\ &\quad - \frac{\left(\frac{\partial E_b}{\partial P} + \frac{\partial E_{cb}}{\partial P}\right)\left((1 + \alpha\bar{\delta})E_b + \alpha\underline{\delta}E_{cb}\right)}{S_b^2} \\ &= \frac{\frac{\partial E_b}{\partial P}[(1 + \alpha\bar{\delta})E_{cb} - \alpha\underline{\delta}E_{cb}] - \frac{\partial E_{cb}}{\partial P}[(1 + \alpha\bar{\delta})E_b - \alpha\underline{\delta}E_b]}{S_b^2}, \end{aligned}$$

which is negative when

$$(A.7) \quad \frac{\partial E_b}{\partial P} E_{cb} < \frac{\partial E_{cb}}{\partial P} E_b,$$

where

$$\frac{\partial E_b}{\partial P} = \frac{\partial E_{cb}}{\partial P} = \frac{1}{D'}.$$

Therefore (A.7) reduces to $E_{cb} < E_b$, which holds when $E_b/S_b > 1/2$. ■

PROOF OF PROPOSITION 9.

- (i) See Proposition 2.
- (ii) We have that

$$E_c = \frac{1 + \frac{1}{\alpha\underline{\delta}}}{A} w + \frac{\bar{R}}{A}.$$

Hence,

$$\frac{\partial E_c}{\partial \alpha} = -\frac{1}{A\alpha^2\underline{\delta}} w + \frac{1 + \frac{1}{\alpha\underline{\delta}}}{A} \frac{\partial w}{\partial \alpha} < 0$$

by (i). Since L_c is fixed, it follows that

$$\frac{\partial(E_c + L_c)}{\partial\alpha} < 0.$$

(iii) We have that

$$E_b = \frac{1 + \frac{1}{\alpha\bar{\delta}}}{A}w + \frac{\bar{R}}{A}.$$

Hence,

$$\frac{\partial E_b}{\partial\alpha} = -\frac{1}{A\alpha^2\bar{\delta}}w + \frac{1 + \frac{1}{\alpha\bar{\delta}}}{A} \frac{\partial w}{\partial\alpha} < 0.$$

We have that

$$E_c + E_b + L_c + L_b = P.$$

Since L_c is fixed, it follows that

$$\frac{\partial L_b}{\partial\alpha} = -\frac{\partial E_c}{\partial\alpha} - \frac{\partial E_b}{\partial\alpha} > 0.$$

Furthermore,

$$\frac{\partial(E_b + L_b)}{\partial\alpha} = -\frac{\partial E_c}{\partial\alpha} > 0.$$

- (iv) Given that L_c and P are fixed whereas $\frac{\partial E_c}{\partial\alpha} < 0$, an increase in α reduces the share of population at the center, $\frac{\partial(\frac{E_c+L_c}{P})}{\partial\alpha} < 0$.
- (v) It follows from (ii) and (iii) that

$$\frac{\partial\left(\frac{E_c + E_b}{P}\right)}{\partial\alpha} < 0.$$

- (vi) Since $S_c = E_c$, it follows that $\frac{\partial S_c}{\partial\alpha} < 0$.
- (vii) Since $S_c = E_c$ and L_c is fixed, it immediately follows that

$$\frac{\partial\left(\frac{L_c + E_c}{S_c}\right)}{\partial\alpha} = \frac{\partial\left(\frac{L_c}{E_c}\right)}{\partial\alpha} > 0. \quad \blacksquare$$

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