How Close Is Close?
The Spatial Reach of Agglomeration Economies

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Abstract

This paper considers the attenuation of agglomeration economies. Put another way: how close is close? The paper presents evidence of agglomeration effects operating at various levels of spatial aggregation, including the regional, metropolitan, and neighborhood scales. In fact, agglomeration effects also seem to operate below the neighborhood level, including within buildings and organizations. These effects attenuate, with nearby activity exerting the strongest effects. The attenuation of agglomeration economies has implications for urban spatial structure, the microfoundations of agglomeration economies, and commercial real estate. It also affects the ability of governments and businesses to internalize agglomeration economies.

I. Introduction

Cities exist because firms and workers benefit from spatial concentration. One benefit arises from the natural advantages present at some locations. Another is that spatial concentration allows for more diverse or less costly consumption by a city's residents. We will be concerned here with another force: agglomeration economies, production benefits that increase with spatial concentration. In considering agglomeration economies, our focus will be geographic. Implicit in the idea that spatial concentration increases productivity is another idea: the degree of proximity matters. Agglomeration economies must decay with distance. How close, then, do firms and workers need to be to each other to benefit from agglomeration economies? Or, more colloquially, how close is close?

Our answer to this question draws on a range of research. Despite significant differences in data and methods, this research reaches similar conclusions. Evidence indicates that agglomeration effects operate at various levels of spatial aggregation, including regional, metropolitan, and neighborhood scales. In fact, there is also evidence that agglomeration effects operate below the neighborhood level, including within buildings and organizations. Although agglomeration effects can extend over broad distances, they attenuate, with nearby activity exerting the strongest effect on productivity.

The spatial reach of agglomeration economies is important for several reasons. First, it sheds light on the forces that generate agglomeration economies, as noted in Rosenthal and Strange, 2001. Marshall (1890) argues that there are three sources: input sharing, labor market pooling, and knowledge spillovers. Other microfoundations have also been proposed. Some of these build on Jacobs' (1961) idea that spatial concentration facilitates unplanned or random interactions (e.g., Vernon, 1963). In considering these microfoundations, the different forces almost certainly operate at different geographic scales, implying that evidence regarding the attenuation of agglomeration economies is relevant to understanding their nature. Sharing of physical inputs, for example, is often associated with truck transport and can extend over regional distances. Labor market pooling is likely to have effects within commuting areas, which is to say at the metropolitan level. Knowledge spillovers as envisioned by Marshall (1890) are unplanned, and so are likely to be highly local. While it is true that information technology allows for effective communication with distant partners, these distant interactions are

complementary to in-person interactions facilitated by close proximity (Charlot and Duranton, 2004 and 2006).

Second, the how-close question also bears on how public and private institutions affect agglomeration and their potential to increase productivity. To the extent that agglomeration economies operate at great distances, it is not possible to exclude migrant firms and workers from the benefits of agglomeration. This limits the ability of governments to internalize agglomeration economies through zoning or other mechanisms. On the other hand, if agglomeration economies were to be highly local, then it would be possible for a "developer" (Henderson, 1974) to control enough land to exclude, and problems associated with public goods would not be as severe. Industry parks can be seen in this sense. Similarly, the smaller is the scale at which agglomeration economies operate, the greater is the power of local governments – all of which have specific geographies over which they are empowered – to control agglomeration effects. Cities have the capacity to manage highly local agglomeration effects without the involvement of higher levels of government. At an even narrower level of geography, if agglomeration economies operate within individual buildings, building owners have incentives to manage the composition of tenants through rent discounts and other devices as are often used to lure in anchor tenants.

Third, the spatial reach of agglomeration effects matters crucially for important markets, including commercial real estate and transportation, causing some locations to be valued over others. Agglomeration economies are certainly capitalized in commercial real estate rents and prices and affect the design of transportation networks that govern the ability of workers to concentrate spatially.

Fourth, the tendency for agglomeration economies to attenuate drives urban spatial structure. This includes the existence of large metropolitan areas and industry clusters, in addition to the ubiquitous downtown business district, often ringed by pockets of intensive commercial activity in suburban subcenters.

Together, these ideas suggest that the evolving nature of proximity will have implications for the future of cities. Because of the information technology revolution, distance is not the barrier it once was. In this new world, will cities retain an important role in productivity and growth? What forms and functions will future urban areas take?

In addressing these questions, this paper will review research on the attenuation of agglomeration effects, integrating into the text freshly documented spatial patterns of employment that will help to motivate and guide portions of the discussion. We begin by reviewing evidence on agglomeration effects at the metropolitan level, where most prior research has focused. Our lens then narrows to the neighborhood level, and from there to below the neighborhood level, establishing that agglomeration effects not only extend across distances as broad as a metropolitan area but are also specific to neighborhoods, streets, and even individual buildings.

II. Agglomeration in Metropolitan Areas

How close is close? Fairly far, according to the approaches taken in the literature on agglomeration economies, which has largely analyzed agglomeration at the metropolitan area and regional levels.[1] Before discussing this literature, we will illustrate the patterns of agglomeration in a series of maps, Figures 1 to 3. These figures show agglomeration effects that operate at high levels of spatial aggregation, as in the literature. They also suggest, however, effects operating at a much tighter level of geography. This section will consider the former, while the latter is considered later in the paper.

To begin, Panel A of Figure 1 displays a map of the spatial distribution of total employment across all industries for the northeast region of the United States, from Virginia and West Virginia up through northern New England. The story that the maps tell does not depend on this particular regional focus. The map was created using establishment level data from Dun & Bradstreet for roughly 8.9 million establishments that collectively employ over 56 million workers.[2] All of the data were downloaded in May and June of 2019 and are current as of that time. To display the data, each establishment was first geocoded at the 3-meter level of precision based on its latitude and longitude reported in D&B. A two-by-two-mile grid was then laid down over the entire northeast region. Employment at the geographic centroid (or node) of a given grid square was set equal to the weighted sum of employment across all establishments out to 10

[1] On an even larger global scale, the gravity literature in international economics shows that trade between countries diminishes with distance. See Isard (1954), Isard and Peck (1954), Tinbergen (1962) and the recent survey by Head and Mayer (2014).

[2] Syracuse University has a site license for Dun & Bradstreet data which enabled us to work with the establishment level information.

miles from the node. This was done using inverse distance weighting (IDW) with exponential decay so that employment at more distant establishments was down-weighted at an exponential rate.[3] The grid square was then assigned a color based on the level of employment assigned to its node. Calculated in this fashion, Figure 1 displays a smoothed representation of the spatial variation in employment over the northeast region.

Several patterns are apparent in the figure. First, and as is well-known, employment is heavily concentrated in major cities like Washington DC, Philadelphia, New York City, Buffalo and other urban centers. Second, concentrations of employment are also often found adjacent to major interstate highways as they pass through rural areas between employment centers. This is clear along the east-west Route 90 corridor that connects Albany with Buffalo and the north-south Route 91 highway that runs up through Hartford and Springfield. Route 95 from Washington DC up the coast through to Boston displays a nearly continuous corridor pattern of concentrated employment. These patterns contrast sharply with large areas of rural countryside that are often within a short drive of urban centers. Third, the coastal cities connected by roads comprise an industrial belt, an agglomeration of agglomerations, suggesting effects that go beyond any single metropolitan area.

The patterns in Panel A suggest that there is some aspect of the dense locations that is highly valued. Cities are expensive places to live and to do business, with high costs of labor and space. Businesses tolerate such costs only if urban locations enhance productivity by an amount sufficient to offset higher input costs. The mechanisms by which this occurs lie at the root of any answer to the question of how close a company must be to nearby activity to benefit from productivity spillovers.

Panel B of Figure 1 provides further guidance by plotting the spatial distribution of sales per worker at single-site establishments over the Northeast Region. Sales per worker is used here to proxy for productivity. The figure was constructed using the same D&B data as above, with the sample limited to single-site establishments. Restricting the sample in this fashion is necessary to ensure the accurate matching of sales to establishments.

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[3] The formula used for these purposes is given as $E_{node} = \sum_{i=1}^{n} E_i/d_i^2 / \sum_{i=1}^{n} 1/d_i^2$, where E_i is employment at establishment i located d_i miles to the grid square node, and E_{node} is the weighted sum of employment assigned to the node. For the plots in Figure 1, the search radius was set to 10 miles so that all establishments $i = 1, \ldots n$ for which $d_i \leq 10$ miles were given positive weight while establishments beyond 10 miles received zero weight. See the MapInfo manual or other standard GIS references for related details in IDW smoothing.

Three patterns are especially striking relative to the employment patterns in Panel A. First, the corridor along the coast from Washington DC up to Boston displays unusually high levels of productivity as proxied by sale per worker, mirroring employment patterns in the first panel. Second the differences between big cities and rural areas are much smaller than in Panel A; many outlying areas also display relatively high productivity. The coast of Maine, for example, exhibits an unusual concentration of high-productivity locations. Third, the extent of variation in sales per worker across locations is far narrower than the corresponding extent of variation in spatial patterns of employment. In Panel A, there is roughly a two orders of magnitude difference in the scale of employment between the lowest to the highest density level indicated in the key, from below 500 to 15,000. In Panel B, the highest coded level for sale per worker (80,000) is just one-third higher than the lowest coded level (60,000).

Together, the patterns in Panels A and B make clear that employment is highly spatially concentrated, while productivity, although higher in large urban centers, is much less so. This echoes evidence that doubling city size increases productivity but by a comparatively small amount, typically less than 5% (e.g. Rosenthal and Strange, 2004; Combes and Gobillon, 2015; Jales, Jiang and Rosenthal, 2019). This suggests that businesses require only modest returns to choose a higher density location over a less heavily developed area. The plots in Panels A and B of Figure 1 tell a similar story.

Figure 2 revisits these issues by focusing on the clustering of industries rather than overall agglomeration. The figure includes four panels, A-D. Panel A repeats the employment panel of Figure 1 for all industries combined. Panel B highlights employment in the manufacturing sector (SIC 20-39). Panel C describes employment in high value finance (SIC 62 and 67, security & commodity brokers and holding & other investment offices, respectively), and Panel D plots employment in research and development (SIC 8731 and 8734, commercial physical & biological research and testing laboratories, respectively). To facilitate comparison of the spatial patterns across industries, the cut-off points in the keys for Panels B-D were set equal to the cut-off points used in Panel A scaled by the respective industry share of employment throughout the northeast region. Adjusted in this fashion, the relative difference in employment across different tone levels of shading are identical across panels. This ensures that two industries that are similarly spatially distributed will have identically shaded maps. Differences

across panels in employment levels for a given tone level of shading, in contrast, reflect differences in the size of the industry.

Viewed at the region level, and defining industries as above, the most obvious pattern in Figure 2 is that the spatial distribution of employment for manufacturing, finance and R&D is broadly similar to that of aggregate employment, with employment concentrated in the large cities along the corridor between Boston and Washington, D.C. There are differences, however. Finance and R&D are underrepresented in rural areas, in contrast to manufacturing and total employment. Close inspection also reveals that finance is unusually concentrated in the New York metro area and that R&D is often found in localized pockets in otherwise lightly developed areas. The latter reflect in part the presence of research institutes such as the famous Woods Hole Oceanographic Institute in Woods Hole, Massachusetts, as well as research parks adjacent to rural universities as with Virginia Tech University in Blacksburg, Virginia and Cornell University in Ithaca, New York. This is consistent with research on universities as partners in knowledge creation and transmission (e.g. Hall, Link and Scott, 2006; Andersson et al, 2004, 2009).

Figures 1 and 2 correspond to an extensive body of theoretical research examining agglomeration at the metropolitan level. See Behrens et al (2015) for a recent survey. The research builds on the theory of systems of cities (Henderson, 1974). One conclusion of such studies is that agglomeration economies help to determine the equilibrium allocation of activity across metropolitan areas, albeit non-uniquely (Helsley-Strange, 2014). Another conclusion is that agglomeration economies affect differences in factor prices across cities, including wages and rent, as in Rosen (1979) and Roback (1982).

The figures are also consistent with empirical studies on the impact of agglomeration economies on spatial patterns of activity (see Rosenthal and Strange (2004) and Combes and Gobillon (2015) for reviews). First, there is agglomeration of overall activity at the metropolitan level. Second, there is also industry clustering (a.k.a., localization) at the metropolitan level. Third, there is evidence that agglomeration economies arise from Marshall's input sharing, labor pooling, and knowledge spillovers, as well as from other sources. Fourth, agglomeration economies manifest themselves in higher productivity as indicated through various measures of wages, rents, growth and innovation.

Regarding innovation, there is substantial evidence that is consistent with knowledge spillovers at the metropolitan level. Many studies, beginning with Jaffee et al (1993), have examined spatial patterns of patent citations, while others, including Moretti (2019), have focused on patent production as an indicator of inventor productivity. Audretsch and Feldman (1996) measure new product development directly from reports of new products in industry trade journals. Andersson et al (2009) provide evidence of knowledge spillovers by exploiting a policy-induced decentralization of higher education facilities in Sweden. Treating the establishment of new universities as exogenous, they estimate the impact of universities on indicators of local productivity and innovation. Estimates indicate that more than half of the gain in innovative activity takes place within 8 kilometers of a newly established university.[4] In complementary work, Buzard et al (2017) show that R&D labs are spatially concentrated at various levels of geography including at roughly the metropolitan scale. All of these studies support the conclusion that agglomeration at the metropolitan level is positively associated with innovation.

Some cautionary comments are in order. One is that the papers above draw on many different data sources and methodologies. This complicates comparison across studies. A second is that all studies of the impact of agglomeration on productivity must control for possible confounding effects. For example, productive workers may be drawn to large cities with attractive urban amenities, which would generate an agglomeration-productivity relationship even in the absence of agglomeration economies. Without adequate controls for such sorting, estimates may overstate the productivity gains from urbanization. See Baum-Snow and Ferreira (2015) for a more complete discussion.

A number of approaches have been taken to address these and related concerns. Obviously, richer data can help. Glaeser and Mare (2001), for example, show that the urban wage premium shrinks substantially when controls for worker attributes and worker fixed effects are included. Instrumental variable strategies have also been used, including deeply lagged regressors (Ciccone and Hall, 1996) and geological variables (Rosenthal-Strange, 2008a, and Glaeser-Kerr, 2009). Strategies based on the shape of factor return distributions have been

[4]Keller (2002) considers the importance of distance in international technology diffusion. See also Keller's (2004) survey.

developed in two recent papers (Combes et al, 2012; Jales, Jiang and Rosenthal, 2020). Structural approaches have also been taken (Baum-Snow and Pavan, 2011), as have matching methods that exploit pseudo natural experiments (Greenstone et al, 2010). Despite very different data and approaches, all of these studies report evidence that productivity increases with city size. Moreover, recent studies have used increasingly rich data and powerful identification strategies, contributing to the reliability of the conclusion that agglomeration enhances productivity.

III. Agglomeration at the Neighborhood Level.

Returning to the question of how close is close, this section will answer: close. A range of different empirical approaches reach the conclusion that agglomerative spillovers are stronger for agents who are closer to each other within a metropolitan area than for agents who are farther apart. This leads to the concentration of production in neighborhoods within cities, such as Wall Street.

Figure 3 presents maps that illustrate this. Panel A displays the spatial pattern of total employment for the five boroughs (counties) that make up New York City. Panels B-D zoom in further to Manhattan and display employment patterns for total employment, manufacturing and finance, respectively. In all four panels the data is as before, but employment is mapped at a higher level of precision, with grid squares set to 0.05 miles in width and the search radius over which employment is smoothed extending out to just 0.1 mile. For perspective, 0.05 miles is about one city block in Manhattan when traveling in a north-south direction.

In Panel A it is apparent that employment concentration is far higher in Manhattan than in the rest of the five boroughs. Moreover, as is evident in both Panels A and B, employment in Manhattan is highly concentrated in two locations, one in Midtown, roughly between Grand Central Station and Central Park, and the other at the southern end of the island. This pattern echoes the regional pattern described above: within the largest city in the United States, employment is not uniformly distributed. Instead, it is spatially concentrated in select neighborhoods.

Panels C and D show manufacturing and finance. Once again mirroring patterns at the regional level, employment in both industries is highly spatially concentrated in select neighborhoods. This concentration takes place in different neighborhoods for the two industries

and to different degrees. For manufacturing, this occurs in three zones, including the area just south of Central park, an area about halfway from Central Park to the southern tip of Manhattan, and also at the southern end of the island. For finance, employment is almost exclusively concentrated in the two dominant employment centers in Manhattan, Midtown and Lower Manhattan. The latter constitutes such a dramatic concentration of finance that it is commonly referred to as the Financial District. Outside of these areas finance is very lightly represented and largely not present beyond Manhattan itself.

What can account for these spatial patterns? Climate obviously cannot account for spatial variation in employment density at such a narrow level of geography as in Figure 3. Proximity to port facilities matters for manufacturing but has less value to employers in finance. As a general matter, it is easier to envision a large role for amenities in explaining agglomeration at the metropolitan and regional spatial scales than at the neighborhood level. An alternative explanation is that in-person interactions between people enhance agglomerative productivity spillovers and are more prevalent for agents situated close to each other as opposed to agents who are farther apart. A growing number of studies in the literature provide support for this view, as discussed below.

The theory most relevant to understanding the patterns in Figure 3 includes Ogawa-Fujita (1980), Fujita-Ogawa (1982), and other related papers on spatial variants of agglomeration economies. See Fujita-Thisse (2013) for a review of this literature. Among the many contributions of this literature, perhaps the most important is that it solves endogenously for the location of employment instead of assuming a monocentric city. The solution depends on the tension between worker commuting costs and agglomeration economies, with the latter modeled as a spatial spillover between firms. The former falls as employment decentralizes, with jobs located closer to where workers live. The latter rises since spillovers become weaker between firms that are further apart. The less local are agglomeration economies – in the sense of a smaller increase in the communication costs between agents as the distance between them rises – the more decentralization will be observed, both in the sense of a continuous employment gradient and in the sense of the discrete addition of subcenters. Productivity and its correlates will depend on the spatial extent of agglomeration economies in a parallel way.

There is considerable evidence that agglomeration economies attenuate, with nearby interactions having larger effects than more distant interactions. Rosenthal and Strange (2001)

consider the cross-sectional pattern of localization (clustering) across industries. The paper's primary focus is the microfoundations of agglomeration economies, but the results also shed some light on attenuation. The paper's approach is to regress an industry's level of spatial concentration (localization) on industry characteristics. This is done at the state, county, and zipcode levels of geography. Proxies for the intensity of innovative activity in an industry show a significant association with the industry's spatial concentration only at the zipcode level, not at the other two levels. Proxies for input sharing, in contrast, are more strongly associated with spatial concentration at state levels. Proxies for labor pooling are significantly related to concentration at all three levels. While this does not identify the degree of attenuation of any of these three Marshallian types of agglomeration, it is consistent with knowledge spillovers attenuating the most rapidly.

Baum-Snow (2019) examines the effects of highways on urban spatial structure. In addition to showing that highway construction promotes decentralization, this paper also has implications regarding attenuation based on the principle that the introduction of a highway reduces the cost of accessing central city locations (as in Baum-Snow, 2007). A structural model is then used to back out a company's preference for a central city location relative to a suburban one in the same metropolitan area. The analysis suggests a large elasticity of productivity with respect to more heavily populated central city locations, implying that agglomeration effects are localized.

Business start-ups are also affected by the level and composition of nearby activity. Rosenthal and Strange (2003) work with two such measures, the number of new establishment births and the employment at these new establishments. These are separately regressed on measures of nearby activity for US data and a subset of industries, expressed as the amounts of own-industry and all-industry activity within five miles and for other distance rings beyond five miles. The marginal effect of employment in the five-to-ten mile ring is roughly half of the effect in the zero-to-five mile ring. Rosenthal and Strange (2005) carry out a parallel analysis for New York City only. This paper allows for differentiation between the effects that are within one mile and one-to-five miles away. Again, there is sharp attenuation. The within one-mile effect is roughly twice as large as the one-to-five mile effects for both establishment births and new establishment employment. In a similar vein, Arzaghi and Henderson (2008) consider New York's advertising industry, historically located around Madison Avenue in Midtown. They

estimate a Poisson count model of openings of new single-site advertising companies as a function of proximity to other nearby advertising agencies (and other controls). They find evidence of significant spillovers between advertising companies, with effects that largely attenuate within roughly 750 meters. They argue that their findings are likely reflective of knowledge spillovers, in part because of the highly localized pattern of estimated effects.

Other papers have looked at productivity and its correlates. Rosenthal and Strange (2008a) estimate wage models.[5] Unlike Glaeser-Mare (2001) and most of the rest of the urban wage literature, the paper defines geographic units based on continuous distance measures rather than relying on political boundaries (as with states or counties, for example). Specifically, it examines the relationship between wage and the amount of employment within five miles and between five and twenty-five miles, controlling as usual for worker characteristics. The paper considers two sorts of local density within each distance band: the density of workers with college or university degrees and the density of workers without these degrees. Geological variables related to the cost of density – access to bedrock, seismic and landslide hazard, coverage by water – are used to instrument for the employment regressors. The effect of nearby college educated workers is significant and positively related to wage, but the effect of more distant college educated workers is close to zero. Concentrations of nearby non-college workers, in contrast, significantly reduce wage but also with a sharp attenuation pattern. The latter result is a reminder that agglomeration without sufficient positive spillovers can impede productivity by contributing to congestion.[6]

A very different set of papers has examined the potential for residentially based labor market networks to increase productivity by enhancing the quality of labor market matching between workers and employers. Using confidential census data, Bayer et al (2008) show that workers who live within the same census block are more likely to work at establishments close to each other than individuals who live only a modest distance further apart. A similar pattern is also found in Hellerstein et al (2011) using matched employer-employee data. Moreover, and

[5] Moretti (2004) documents the existence of large human capital spillovers at the metro level.
[6] Analogous attenuation patterns are also evident in Li (2014). Li shows that a greater concentration of in-state doctors within twenty-five miles lowers mortality rates from various diseases relative to similar concentration of more distant doctors. She also shows that state borders reduce the positive effect of nearby medical personnel, consistent with state licensing laws that restrict the ability of doctors to treat patients across state lines. This result provides evidence that local government policy can affect the transmission of agglomeration economies, in this case with negative effect.

also using matched employer-employee data, Hellerstein et al (2014) show that job turnover and wages vary with social connections within a residential neighborhood in ways that support the idea that increased neighborhood connectedness enhances worker productivity. Although this literature does not provide evidence on spillovers between employers, these papers further confirm the general principle that neighborhood-level proximity can foster productive interactions.

Of course, as in Rosen (1979) and Roback (1982), agglomeration effects will be captured not just in wage but also in rent. Wage estimates may, therefore, capture only part of the agglomeration effect. This suggests a research strategy of studying the relationship between agglomeration and the commercial or industrial rent paid by the tenant. Unfortunately, these data are not commonly available, and the great heterogeneity of commercial and industrial real estate means that it will be difficult to have the sort of data that allows an apples-to-apples comparison.

Liu, Rosenthal, and Strange (2018a) overcome the difficulty of obtaining useful rent data by working with confidential offering memos that report rent. The cost of this resolution is that the data are non-representative in that offering memos are generated only when buildings are put up for sale. This paper obtains another result consistent with agglomeration economies operating at the neighborhood level, showing that rents are positively related to the intensity of activity within a building's zipcode. The point estimate suggests that doubling employment within the zipcode is associated with a roughly 11 percent increase in commercial rent. These effects are found for office industries such as law, finance, and business services, precisely the industries that have come to dominate downtowns.

Ahlfeldt et al (2015) takes a different perspective to the attenuation of agglomeration effects by using the exogenous variation in nearby density associated with the construction and demolition of the Berlin Wall. Reduced form estimates show that the Wall hindered access to those parts of the prewar central business district located in East Berlin. Structural estimates of the attenuation parameter imply highly localized productivity spillovers, with effects reaching roughly zero at 10 minutes of travel time. This corresponds to about half a mile by foot and 2.5 miles by subway (respectively, 10 and 50 Manhattan blocks). This is yet another approach, one with strong identification and tight ties to theory, that finds the same result of rapidly attenuating agglomeration effects.

Despite differences in approach, the papers above reach similar conclusions: agglomeration economies attenuate rapidly. For example, Rosenthal and Strange (2003) conclude that spillover effects shrink by roughly half after five miles, while Rosenthal and Strange (2005) find effects that are notably smaller after one mile. Henderson and Arzaghi (2008) report evidence that among advertisers, spillovers attenuate away within 750 meters, or a little less than half a mile. Although measured based on travel time and not distance, results from Ahlfeldt et al (2015) similarly suggest rapid attenuation. There is thus a clear consensus that proximity matters.[7]

As discussed in the Introduction, there are several reasons why the attenuation of agglomeration effects matters. As shown by Fujita and Ogawa's work (1980, 1982), attenuation of agglomeration economies has an important effect on urban spatial structure. It determines whether a city is monocentric and if so how spatially concentrated employment may be. It determines whether subcenters form, and if so how many.[8] More generally, it determines the degree and form of urban sprawl.

The robust result that agglomeration effects are local also has implications for the microfoundations of agglomeration economies. Marshall (1890) identifies knowledge spillovers, labor pooling, and input sharing as potential sources. Jacobs (1961) emphasizes the value of unplanned synergies among residents of large cities. The results discussed above suggest that there exist agglomeration forces that operate when agents are close to each other. Planned and unplanned interactions that contribute to knowledge sharing are likely to be more local in nature, taking place between agents who are familiar with each other. This familiarity is likely to be tied to proximity. Labor markets tend to operate at longer distances; in fact, metropolitan areas are defined in part by commuting flows. Similarly, physical inputs are often transported great distances. This is not to say that there is not a local element to labor pooling and input sharing. Local word-of-mouth job market networks are part of labor market pooling, while input sharing sometimes involves repeated interactions that can be enhanced by face-to-face meetings facilitated by proximity (Vernon, 1963). Our point is instead that the in-person interactions are

[7] It should also be noted that even if agglomeration economies were entirely local, we would still observe agglomeration at a much larger scale due to the overlap of local clusters (as noted by Kerr and Kominers, 2015).
[8] McMillen and Smith (2003) estimate the relationship across a sample of cities between the number of subcenters and a city's population and commuting costs. These two variables are strongly predictive of the number of subcenters, as predicted by the Ogawa-Fujita model discussed earlier. See also Giuliano and Small (1991) and McDonald and McMillen (1998) for further analysis of subcenters.

more central to Marshallian knowledge spillovers, since in-person communications are likely to be more important.

The local nature of agglomeration effects also has normative implications. Hsieh and Moretti (2019) present a quantitative model of agglomeration in order to assess the welfare consequences of land use regulation. To the extent that land use regulation is binding, it raises the cost to a city of accommodating a larger population. This, in turn, means that there is a spatial misallocation, where households and firms are not located in the places that maximize welfare. The calibrations show a large effect. All of this analysis takes place at the metropolitan level. In this setting, the inability to develop at high density in one part of a metropolitan area (say, in very restrictive Toronto) can be overcome if another part (for instance, less restrictive Mississauga) is not similarly constrained. With localized agglomeration effects, this spatial substitution is not possible, implying that the costs associated with binding land use regulation may be even higher.

Another normative implication pertains to the role of entrepreneurial agents who profit from correcting urban resource misallocation. Henderson (1974) refers to these agents as "developers," with the idea that inefficiency will be capitalized into land prices allowing a developer to profit from welfare enhancing policies. There are clearly no agents who can perform this role at the scale of an entire city; even the biggest developer is not this large. However, to the extent that a significant fraction of effects are localized, then a developer will be more likely to be able to internalize the relevant spillovers. For instance, the developers of Canary Wharf's financial district were able to control the entire district. See Helsley and Strange (1997) for further discussion of this issue.[9]

IV. Agglomeration below the neighborhood level

Returning once again to the how-close question, we now zoom in even more tightly, and show that for agglomeration economies, how-close can mean very close. In other words, in addition to operating at the metropolitan and regional levels, and also at the neighborhood level, agglomeration economies operate well below the neighborhood level.

[9] Another institution for internalizing spillovers is the Business Improvement District, in which local business owners form an association and act as local "private governments" in order to influence the attributes of the neighborhood business environment with potential to improve efficiency (e.g. Helsley and Strange, 1998).
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One sense in which this is true is that agglomeration economies appear to operate within individual buildings. Liu, Rosenthal, and Strange (2018b) consider the office sector. They show that buildings are specialized even in small business districts that are themselves specialized. We provide graphic evidence of this in Figure 4. The southern end of Manhattan exhibits a well-known specialization in banking and finance (see Figure 3, Panel D). Figure 4 displays all of the buildings in this neighborhood, both in two dimensions (Panel A) and three dimensions (Panel B). In both panels, buildings with a higher finance share of employment are shaded a more vibrant tone of red. Despite the specialization of the neighborhood, most buildings actually have little or no finance, while only a relatively small number of buildings are dominated by financial services. Even within an area famous for financial services, buildings are specialized.

Liu et al (2018b) conduct a more complete assessment of these patterns for finance and other industries that dominate office buildings in city centers, such as law, advertising, and retail. For the neighborhoods adjacent to the NYSE and Grand Central Station, commercial activity is specialized in select buildings beyond what random assignment would imply. This is true even controlling for building quality, which could potentially make some buildings better suited for specific tenants. Furthermore, for roughly 50,000 buildings in the city centers of New York, Chicago, San Francisco, Los Angeles and Washington DC, Liu et al provide evidence that building-level productivity spillovers likely contribute to building-level specialization. The identification strategy focuses on the relationship between the presence of an anchor establishment and the composition of other commercial activity in the anchor's building and also employment in the adjacent building on the same side of the street. Controlling for building fixed effects and the composition of employment within roughly two blocks, evidence indicates that when an anchor is present, other establishments in the anchor's building display 15 to 18 percent higher employment in the anchor's own industry. This effect drops to just one percent, however, for the adjacent building on the same block face. These patterns support the view that productivity spillovers associated with proximity to anchor establishments draw complementary companies together and that such spillover effects decline sharply upon leaving the building.

In fact, specialization may take place at an even smaller geographic scale. Liu, Rosenthal and Strange (2020) show that within tall commercial buildings employment per square foot of office space is higher when an establishment has other establishments in its industry on its floor. This effect is also significant on the immediately adjacent floors, up or down, although it is

reduced by more than half. The effect largely attenuates away by three floors distance. Since establishment employment density increases with productivity as a company grows and adds more workers to existing space, this pattern is consistent with within-building productivity spillovers that dissipate once vertical distance exceeds typical stairwell walking distance, at which point elevator travel is used. So agglomeration effects seem to take place within buildings or even between adjacent floors in a building.

This leads naturally to the question of whether there are spatial effects operating even within establishments and firms. Since these effects are internal to firms, there is a sense that they are not spillovers in the classic sense. However, they are spatial effects that are external to individual workers. Charlot and Duranton (2006) document the substantial amount of communication taking place within a firm. Mas and Moretti (2009) show that the presence of an unusually productive worker in a supermarket enhances productivity of other workers in the store. This effect is strong when the productive worker is on the same shift and visible to other workers but weak otherwise. Sandvik, Saouma and Seegert (2019) provide analogous evidence based on an experimental design. They show that increased communication between co-workers in sales call centers increases productivity in ways indicative of knowledge sharing and learning from peers. In a completely different setting, Bosquet and Combes (2017) show that economists in French universities develop more successful publication records when there are other academics in their department with a similar field of emphasis. To the extent that spillovers are within firms and other organizations, both the capacity and the incentive to address spillovers are present.

In fact, the capacity and incentive to internalize spillovers are even stronger. We previously observed that the geographic scale of agglomeration economies had implications for the ability of agents to internalize agglomeration spillovers. While developers only rarely control entire commercial or industrial districts, individual buildings are owned by agents with the capacity and incentives to manage spillovers. This idea is familiar in the context of shopping malls, a particular type of commercial structure. In that context, it is standard practice for mall owners to seek big-box anchor tenants that are perceived as generating positive shopping spillovers that attract additional smaller tenants. This idea is found in theoretical work by Brueckner (1993) and Konishi and Sandfort (2003) and empirical studies by Pashigian and Gould (1998), Gould, Pashigian, and Pendergast (2005). It is also present in Koster, Pasidis and

van Ommeren (2019) who provide evidence of spillovers on shopping streets outside of a mall context. The finding of highly localized spatial interactions implies the possibility of internalization without government intervention.

All of this means that we see evidence of agglomeration effects operating at the metropolitan scale, the neighborhood scale, and below the neighborhood scale. The latter includes effects operating within individual buildings and even floors within buildings. These are very local spatial spillovers indeed.

V. Conclusion

How close is close? Taken together, the evidence presented in this paper shows that agglomeration effects operate at various spatial scales, with nearby effects the strongest. This pattern can reflect a number of forces. First, it may reflect a single agglomeration effect with spillovers decreasing with distance. For example, the labor pooling benefits enjoyed by employers are likely to shrink as they become farther apart, since worker commuting costs to an alternate employer will tend to increase. Second, it may reflect the combined effects of multiple agglomeration forces, where the individual forces have different ranges. Knowledge spillovers are likely to operate at a narrower spatial level than labor pooling, for example. Finally, there may be heterogeneity among agents in their interaction costs. All agents can presumably benefit from activity that is very close, but some may not be sufficiently "networked" to benefit from interactions further away. This is one way to interpret the Rosenthal-Strange (2012) analysis of female entrepreneurship, which presents evidence consistent with female entrepreneurs enjoying less benefit from agglomeration than male entrepreneurs.

The continued importance of proximity is notable in light of the huge reductions in interaction costs witnessed in recent years. In considering why proximity continues to matter, Glaeser (1998) proposes three key transport costs he sees as driving the future of cities: the costs of moving ideas, people, and goods. Road building and other transport improvements have certainly affected the costs of moving people and goods, making it easier to access employment centers from greater distance. This was documented by Baum-Snow (2007) who shows that radial urban highways contribute to decentralization of U.S. cities and growth of the suburbs in urban areas. A parallel transport mechanism likely helps to explain the concentration of employment along major highways in otherwise rural areas as noted earlier in the discussion of

Figure 1. Analogously, Dong, Zheng and Kahn (2020) show that the recent introduction of high-speed bullet trains in China have contributed to increased partnerships and co-authorship among scholars in universities in different cities. This reminds us that the physical transportation costs associated with interaction can also affect the cost of moving ideas, extending the spatial reach of knowledge spillovers and diffusion of ideas at the regional scale.

Since Glaeser's (1998) paper, the IT revolution has surely affected his three sorts of transport costs in ways that at first glance might be expected to contribute to greater dispersion of activity. This includes the many changes associated with electronic communication that have reduced the cost of sharing ideas from afar. It also includes recent innovations like ride sharing which have reduced the cost of travel within a metropolitan area (Hall, 2018).[10]

Despite all of these innovations, we continue to see evidence of agglomeration effects operating at highly local spatial scales. These scales include neighborhoods, individual buildings, and even spatial arrangements of workers within buildings, all of which have potential to foster local interactions. It is worth noting, however, that there has been no work in the literature on the economics of agglomeration that has carefully considered the effect of dramatic reductions in interaction cost on changes in the spatial scale at which agglomeration economies operate. Returning to the maps from earlier in the paper, it is notable that the Northeast's large cities at the founding of the U.S. are mostly the large cities we see today. There are, of course, new cities that arose in other places, but the historic cities remain important. Since the technological forces governing agglomeration have changed profoundly, this implies that equilibrium patterns of agglomeration change slowly, consistent with evidence from Bleakley and Lin (2012) and others. Another reason for the continued importance of highly proximate interactions may be that they are complementary to more distant interactions that new technology now allows. An example would be the potential to first establish partnerships in person that could then operate effectively from remote locations in subsequent years.

It is also worth emphasizing that the IT revolution is fairly recent, and so its effects on urban form and function are likely still evolving. Online retail, for example, is new and growing rapidly. While internet purchases have the potential to draw retail activity out of city centers, online retail is not a substitute for the appeal of window shopping or the buzz of night life on a busy street. To the extent that such urban amenities have disproportionate appeal to high-

[10] Presumably, the deployment of autonomous vehicles will also reduce travel costs.

productivity workers, this may contribute to gentrification and a rising concentration of college educated residents in city centers, as recently documented by Couture and Hanbury (2019). An analogous amenity-based mechanism likely explains the tendency for high productivity establishments to concentrate high in tall commercial buildings where views are more dramatic, as recently documented by Liu, Rosenthal and Strange (2018). Although our focus here is on the spatial reach of productivity spillovers, localized and endogenously created amenities will contribute to concentrations of skilled workers. That in turn may amplify localized productivity spillovers. This would be consistent with evidence from Rosenthal and Strange (2008a, 2008b) and Mas and Moretti (2009) that proximity to productive workers tends to boost performance.

In sum, improvements in information technology have still left us with agglomeration economies that operate at both broad and narrow spatial scales. Information technology clearly allows for productive distant interactions. An example is a radiologist reading an x-ray from a remote site. Other examples include the increasing use of video conference business meetings that take advantage of increasingly effective remote communication software, reinforced by distant interactions necessitated by the coronavirus pandemic. Nevertheless, both through direct and indirect channels, a range of evidence all points to continued benefits from proximity at narrow levels of geography, including neighborhood, building, and even within-building locations.

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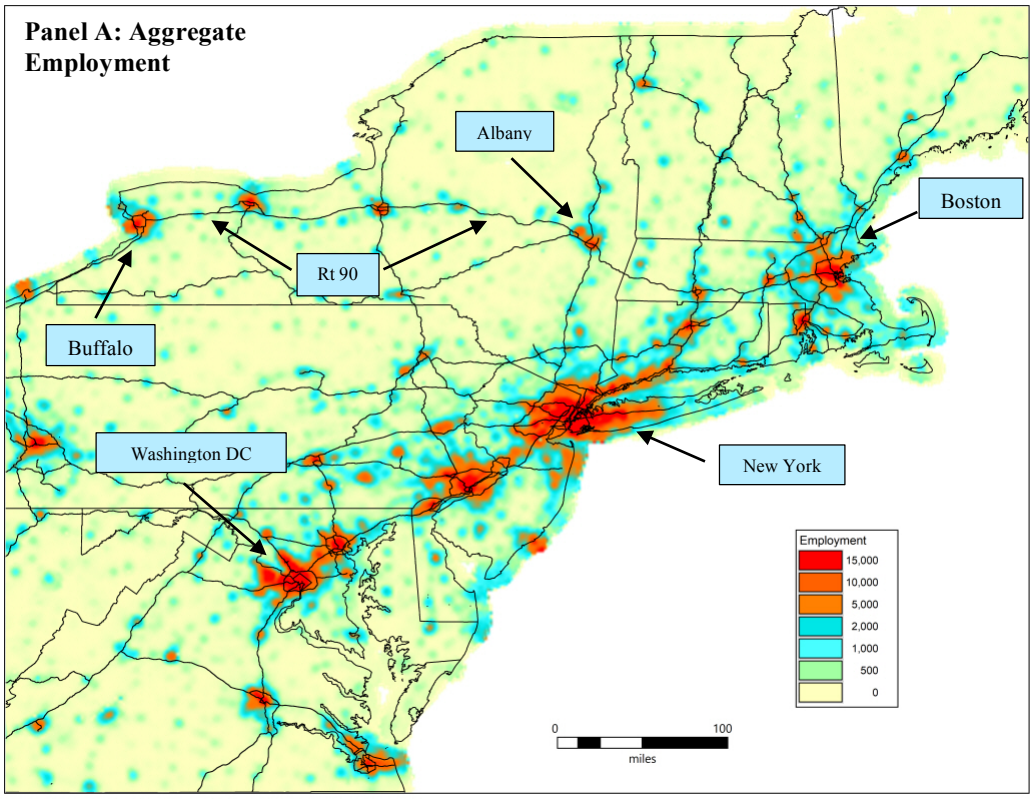
Figure 1: Aggregate Employment and Single-Site Average Sale/Worker Within 2 Miles (All values are smoothed out to 10 miles with inverse exponential distance weighting)



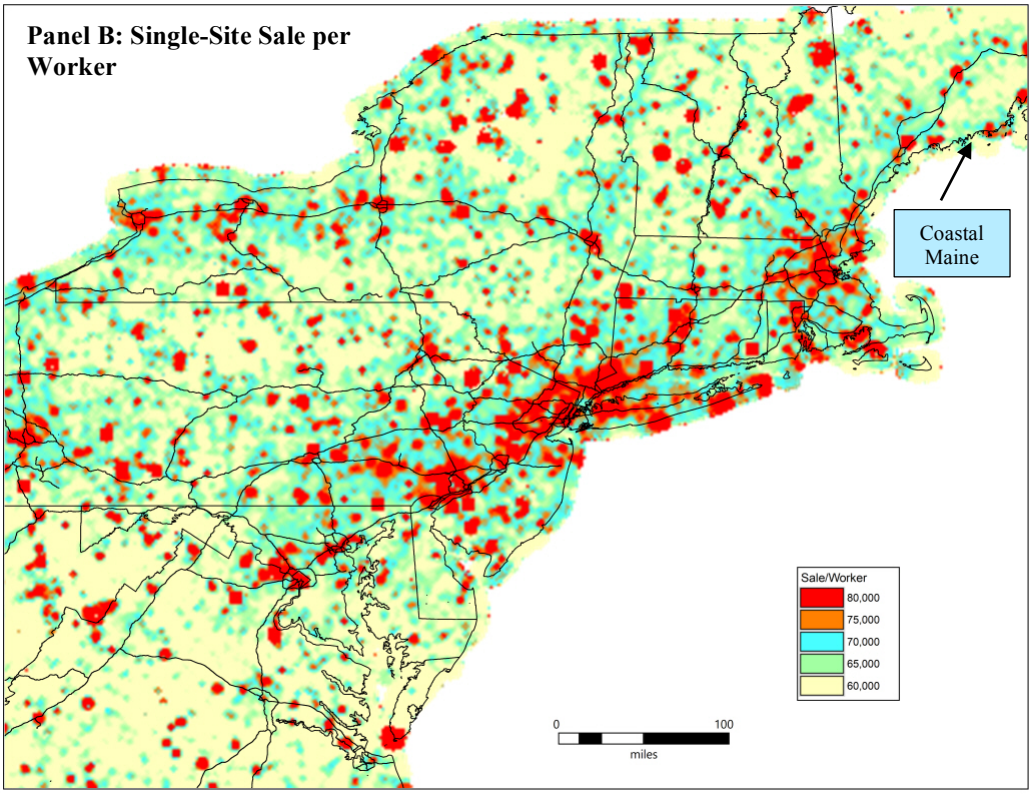


Figure 2: Employment Within 2 Miles For Select Industries
(All values are smoothed out to 10 miles with inverse exponential distance weighting)

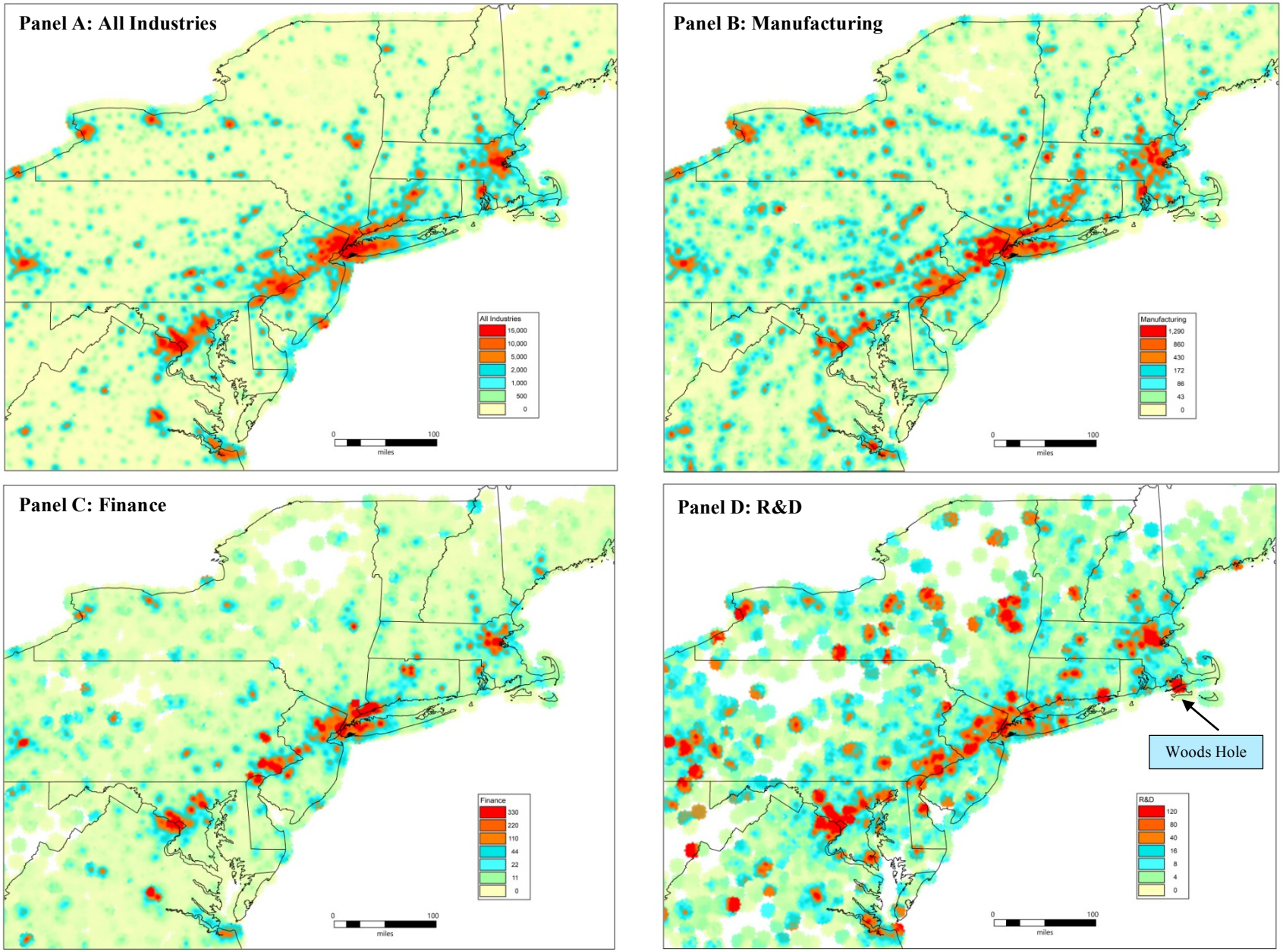


Figure 3: Employment Within 0.05 Miles in the Five Boroughs of New York City
(All values are smoothed out to 0.1 miles with inverse exponential distance weighting)

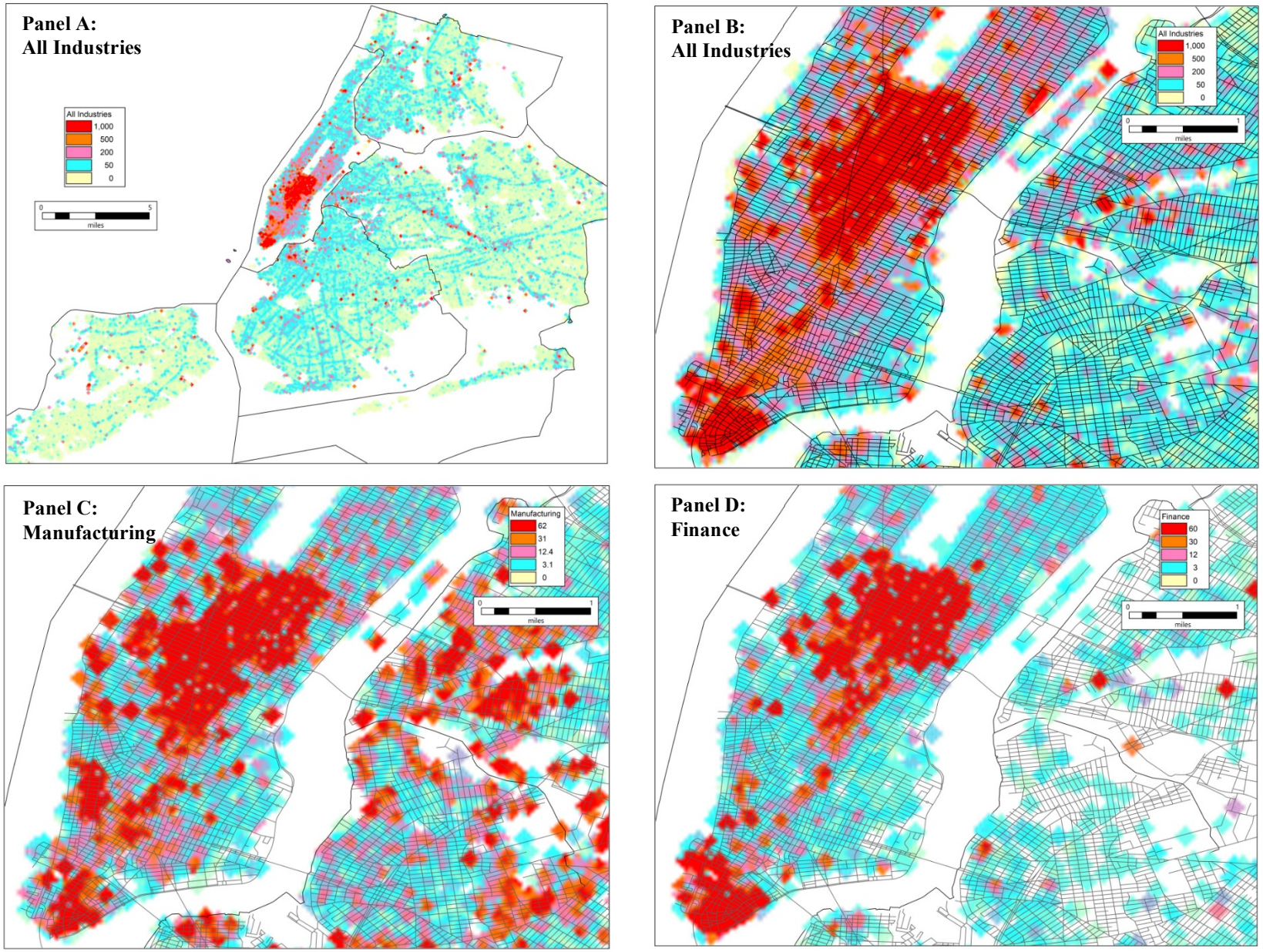


Figure 4: Finance Share of Employment (SIC 62, 67) In the Financial District