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COMMUTING AND THE SPATIAL STRUCTURE OF AMERICAN CITIES:

The dispersal of the great majority of workplaces away from CBDs, employment sub-centers, and live-work communities.

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ABSTRACT

Urban transport and land use policy are informed by our perceptions of the prevailing spatial structure of cities. This structure can be characterized by five models: The Maximum Disorder model, The Mosaic of Live-Work Communities model, the Monocentric City model, the Polycentric City model, and the Constrained Dispersal model, where the great majority of jobs are dispersed throughout the metropolitan area and where workers and workplaces in a metropolitan-wide labor market adjust their locations to be within an tolerable commute range of each other. We examine evidence from a stratified sample of 40 U.S. cities and from the 50 largest U.S. cities to show that the latter model best explains the spatial structure of contemporary American cities. The Constrained Dispersal model is, in essence, a hybrid model that combines elements of all other models. It postulates that the Maximum Disorder model is largely correct, except that it applies only to 3 out of 4 jobs but not to all jobs, and except that commuters and workplaces move to be within a tolerable commute distance of each other. It postulates that the Mosaic of Live-Work Communities model is also correct, except that it only applies to 1 out of 12 people, on average, who live and work in the same community. It postulates that the Monocentric City model is also correct, except that only 1 out of 9 jobs, on average—rather than all jobs—still locate at the CBD. And it postulates that the Polycentric City model is also correct, except that only 1 out of 4 jobs, on average—rather than to all jobs—locate in the CBD or in employment sub-centers. In essence, the great majority of workplaces is now dispersed outside CBDs, employment sub-centers or live-work communities, and is beyond walking or biking distance. Maintaining and increasing the productivity of American cities requires a sustained focus on meeting the travel demands of the great majority of commuters rather than on improving mobility at large or on transportation strategies focused on CBDs, employment sub-centers, or live-work communities.

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Introduction

Urban transport and land use policy are informed by our perceptions of the prevailing spatial structure of cities. In the abstract, the term *urban spatial structure* refers to discernible patterns in the distribution of human activity in cities. More specifically, it refers to discernible patterns in the distribution of residences and workplaces in metropolitan areas and in commuting patterns that connect them to each other.

Some of these patterns can be detected with a naked eye: Offices and apartment buildings in the Central Business District (CBD) are typically taller than those on the urban periphery; roads to the CBD in the morning rush hour are typically more congested than roads on the urban periphery; and large metropolitan areas typically have more than one business district with a concentration of tall buildings. But some of these patterns cannot be detected with a naked eye: For example, the share of workers who commute to workplaces outside the CBD; the share of workplaces that are located outside the CBD or outside business districts altogether; or the share of people who live or work in a given community that both live and work in that community. When a spatial pattern cannot be detected with a naked eye, we must first define it and then resort to the analysis of the available statistical evidence to detect it, to measure it using simple metrics, and to confirm its validity and hence its importance for guiding urban transport and land use policy.

When we seek to maintain and improve the performance of our cities—through transport infrastructure investments, through regulatory reforms, or through taxes and subsidies—it is important to understand the relationships between these interventions and the performance of cities. In this paper, we focus on one critical aspect of that performance: their productivity. As we noted in our companion paper, "Commuting and the Productivity of American Cities", the greatest productive advantage of modern-day American cities is that they form large and integrated metropolitan labor markets. The policy implication of this finding is that the more integrated metropolitan labor markets are, the more productive they are. We should therefore support policies that increase the overall connectivity of metropolitan regions for productive travel: Policies that allow for speedier rather than slower commuting, for more rather than less commuting, and for longer rather shorter commuting to take advantage of metropolitan-wide economic opportunities. More generally, we should support policies that meet the travel demands of the great majority of commuters, making it easier for them—or, at the very least, not more difficult for them—to get to their jobs.

Such policies would be quite different in cities with different types of spatial structure. In monocentric cities where most people commute to work in the Central Business District (CBD), we should support commuter railroads, for example, that carry large numbers of commuters to the CBD on radial routes, as well as a dense system of subways, busses and bike lanes within the CBD. In polycentric cities where most people commute to work in the Central Business District (CBD) or in employment sub-centers outside the CBD, we should support commuter railroads that connect employment centers to each other; a dense system of public transport lines and bike lanes within employment centers; as well as regulations that permit mixed land uses—allowing residences and workplaces to intermingle—in employment sub-centers. And if cities were mosaics of live-work communities, we should support regulations that permit mixed land uses, policies that mandate small city blocks that make it easier to walk to work, and policies that promote a network of bicycle lanes throughout the community, giving priority to short-distance local traffic rather than to longer-distance through traffic.

This paper questions whether contemporary American cities conform to any one of these three models. And if they do not conform to any of these models but to yet another model of urban spatial structure, that too has significant policy implications. In the remainder of this paper we define five candidate theoretical models of the spatial structure of cities and present statistical evidence from the cities we studied that may help us decide which one of these models better fits the observed spatial realities of contemporary American cities. Namely, which model better describes the great majority of residence and workplace locations and the commutes between them; not a small share, but *the great majority*. This is, no doubt, an important matter for us to decide because our perceptions of the overall spatial structure of cities inform our ideas about what can and should be done—in terms of public plans and investments and in terms of regulatory reform—to improve their land use patterns and their transportation systems in the coming years. And when we seek to improve them, we should maintain a clear focus on improvements that may benefit the great majority of commuters rather than on our pet projects, plans, programs and policies that either ignore the great majority of commuters altogether or assume that they will readily change their residences, workplaces and commute patterns in response to fuzzy grand visions premised on "if we build it, they will come".

The paper is divided into four sections. In section I, we survey the forces that shape the spatial structure of cities and introduce five candidate theoretical models that may or may not capture the key attributes of the spatial structure of contemporary American cities. In section II, we present the evidence for favoring one of these models or another. In section III, we examine the implications of our findings for transport and land use policy. Finally, we summarize the sources of data and the methodology used in our study in two Annexes at the end of the paper.

I Five Models of Urban Spatial Structure

In this section, we survey the forces that shape the spatial structure of cities and introduce five candidate theoretical models that may or may not capture the key attributes of the spatial structure of contemporary American cities.

1. Urban spatial structure and the forces shaping it

Urban spatial structure comes into being through the interplay of four types of forces. First, there are forces that *compel people to live closer or further away from other people*. People form families that share homes. People of similar economic, cultural, ethnic, place of origin, or religious backgrounds want to be near people like themselves and often congregate in closely-knit neighborhoods. People without means are often forced to live together in rundown neighborhoods. Conversely, people move away from other people with whom they do not feel comfortable or from neighborhoods that feel unsafe. Rich people move away from poor people and seek to exclude them from their neighborhoods by creating gated communities, by insisting on minimum lot size zoning, or by forbidding the construction of multi-family structures in their neighborhoods and towns. And some urbanites, while still employed in the city, prefer to move away from other people altogether to live in pastoral rural surroundings beyond the urban edge. Last but not least, people's homes and the services and amenities associated with them occupy land and the more land they consume, the further away from each other they find themselves.

Second, there are forces that *compel people to live closer or further way from their jobs*. People naturally seek homes in locations that are accessible to job opportunities. When commuting costs are very high relative to incomes or when people have strong aversion to commuting, they seek residences that are within walking or biking distance from their jobs, or jobs that are within walking or biking distance from their homes. Similarly, firms seek to locate near their workers or potential workers so as to reduce their commuting costs. They also seek to locate in metropolitan areas with large labor markets, so that they can better match labor to their special needs, so that they can maintain a flexible labor force, and so that they can share with other firms the risks brought about by changes in their labor profile. Conversely, when commuting costs to the best available job are low and commuting is not unpleasant, people may be willing to commute a long distance away as long as their workplace is within a tolerable range, say within half-an-hour or, for a minority, within one hour. People may opt to live further away from jobs when competition for space near jobs raises their cost of housing, and when they can live in cheaper and bigger houses further away from their jobs. People may also be separated from job locations by zoning regulations that keep them apart, forcing a strict separation between industrial and residential areas, by rent control that may prevent them from moving closer to their jobs, or by exclusionary zoning regimes that restrict the availability of affordable homes closer to their jobs.

Third, there are forces that *compel jobs to be closer or further away from each other*. Firms that can become more productive by employing more workers assemble many workers together into one factory or into one office enclosure, bringing their jobs closer together. Shopping centers that can attract more shoppers by offering a wider range of goods bring together many workers as well. Researchers that benefit from exchanging ideas congregate together in campuses. Lobbyists want to be in regular face-to-face contact with politicians. Industrial establishments or corporate offices that share the same infrastructure and local amenities congregate. Passenger and cargo airlines congregate to share runways, and industrial firms that ship bulk materials in and out congregate near railway terminals. Firms using the same labor force, say software, aerospace or automotive firms, may seek to cluster in one metropolitan area or another, or within metropolitan areas. Conversely, firms may seek to locate away from other firms so as to capture a larger share of their consumer market. They may also seek to escape areas that have large concentrations of businesses, where roads are congested, parking is scarce, and land rents are high, preferring more peripheral locations where they can inhabit single-story structures with ample parking and direct access to high-speed highways.

Finally, there are forces that compel both people and firms to locate closer or further away from features of the urban landscape. People prefer homes with a view of the sea, the lake, or the mountains in the distance. They are also drawn to historical districts with a colorful architectural past. Businesses prefer locations with direct access to a natural port or to a river that can carry boat transport and provide fresh water. Both people and firms generally prefer locations that are flat rather than hilly or mountainous, where the building of cities is cheaper. And both may prefer locations where ground water is plentiful.

All of these forces act together to determine the spatial structure of cities. Their relative influence may wax and wane over time, and may vary considerably from one city to another at any one time. They may not be directly observable, and it may be quite difficult to dissect the spatial structure of a given city to determine what constellation of forces compelling people and jobs to be closer or further away from each other gave rise to it and how powerful one force was relative to another.

What does being 'closer or further away' mean in this context? When people come together in families, when workers come together to work on a common task, when shoppers come to a store, when students come to class or when friends meet for dinner they need to *share the same built enclosure*, be it the home, the factory, the store, the office, the classroom, or the restaurant—places where they are always in face-to-face contact. When like-minded people come together to form neighborhoods, when stores congregate to form shopping centers or specialized shopping districts, or when researchers come together to share ideas in a campus they may need to *be within walking distance* of each other, where face-to-face contact is occasional and often spontaneous. When people need to get to work or look for work, visit their friends and acquaintances, shop for something special, or go to a play or to a concert; when firms provide occasional services or deliver occasional goods to other firms; or when professionals need to meet to exchange information, they may only need to *be within a tolerable travel range* of each other, say within a half-an-hour to an hour by car or public transport. Face-to-face contact in these cases is typically intentional and rarely spontaneous. Finally, when people contact each other by phone or email, when people telecommute or order goods and services via the Internet, they no longer need to be close to their friends and acquaintances, to stores, to their classrooms, or to their workplaces at all. They only need to *be connected in cyberspace*, never having to meet face-to-face.

At any one time, every residence and workplace in the city occupies one and only one location, a location relative to the location of all other residences and workplaces, as well as to the features of the urban landscape. Workers and firms locate in response to what is available to them and what is suitable for them. Taking into account the existing configuration of residences, workplaces, and other amenities, as well as the ease of getting from one to another, they then decide on how and when to adjust their locations and their travel patterns. And if conditions change or if their preferences change, they change their locations and their travel patterns. They tend not to change their locations very often because moving from place to place is both costly and time consuming. The observed spatial structure of contemporary cities is then a reflection of this complex process of continued adjustment, an adjustment that—in a dynamic, creative, and innovative urban economy—never quite reaches a stable state. Yet it is never truly chaotic either. There is an underlying order to the spatial structure of contemporary American cities. The aim of this paper is to point to it and to present evidence that may support and discredit it.

2. Five candidate theoretical models of the spatial structure of cities

Most of us urbanites spend a substantial portion of our days at home, at our job, and at getting from home to work and back. Where we live and where we work matter a great deal to us. And getting to work and back—although constituting only one quarter of trips we make (data for 2009, AASHTO 2013, table 2.1, 9) and not necessarily the most enjoyable trips we make—are the most important trips we make. It is those trips that sustain us, and it is those trips that make us, and our cities, productive. In the foregoing discussion, we shall limit ourselves to working people, their homes, their workplaces, and the patterns of travel between them. We will largely focus on the city as the locus of production, and only indirectly on the city as a locus of consumption. And we will limit ourselves to describing the very coarse spatial structure of metropolitan areas in broad brushstrokes, rather than providing a detailed description of their social and economic ecology. In this section we introduce five candidate theoretical models of the overall spatial structure of contemporary American cities: the Maximum Disorder model, The Mosaic of Live-Work Communities model, the Monocentric City model, the Polycentric City model, and the Constrained Dispersal model. Each model has different policy implications regarding urban transport and land use.

The first model is the *Maximum Disorder* model. It stands at one extreme of possible urban spatial structures. It assumes the absence of any forces of attraction or repulsion between residences and workplaces, among residences, among workplaces, or between both and other features of the urban landscape. Where both transport costs or nuisance costs are zero or negligible, we can imagine a city where residences and workplaces are located everywhere, and where randomly located workers commute to randomly located workplaces. We define the model as follows,

> *The Maximum Disorder* model: Workers' homes and their jobs are randomly distributed throughout the metropolitan area, and workers commute from a random residence to a random job.

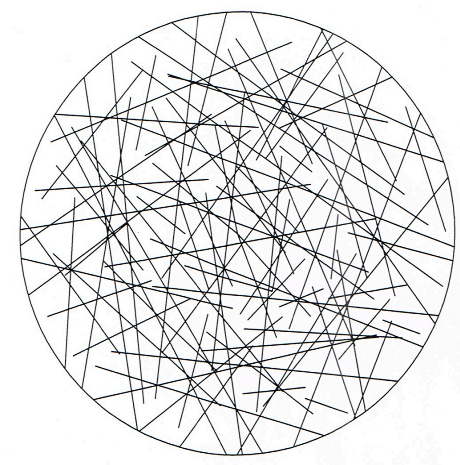

Figure 1: The *Maximum Disorder* Model.

In this model (see figure 1), there is no reason for workplaces to congregate, not near a special feature of the urban landscape, say a port, and not near each other. Workplaces are footloose and can locate anywhere. There is also no reason for neighborhoods of homogeneous households to form. There is no reason for workers to move their homes so as to be closer to their jobs or to crowd themselves in close proximity to their jobs. There is no advantage to one location over another, and the real estate adage "location, location, location" loses its meaning. If there is any clustering of residences or jobs in the city, it is only due to chance: random distributions of points in space always produce clusters here and there. This, then, is a model of the ultimate fragmentation of the city into its basic building blocks—residences and workplaces—where no observable structure or order emerges beyond that expected of random distributions. In an important sense, therefore, this model is the baseline for the study of urban spatial structure, the *null hypothesis* of statistics. Any claim that observable structure or order does exist in a given city must produce evidence that rejects the hypothesis that this order could have been produced by a random distribution with a high degree of statistical confidence.

The second model is the *Mosaic of Live-Work Communities* model. It stands at the opposite extreme of possible urban spatial structures to the Maximum Disorder model. In this second model, the attraction between residences and workplaces is very strong, in other words commuting costs are very high either because of limited transport technology or because of the strong preferences for working at home or walking or bicycling to work. The attraction between homes is strong as well: everyone working in the community also lives there. The attraction between workplaces, however, is weak and they can comfortably disperse into discrete communities. The resolution of this set of forces leads to the formation of a city with a mosaic of small, discrete, and identifiable live-work neighborhoods throughout the metropolitan area. We define the model as follows,

> *The Mosaic of Live-Work Communities* model: The metropolitan area is a mosaic of discrete live-work communities, where workers' homes and their jobs are all within walking or bicycling distance of each other.

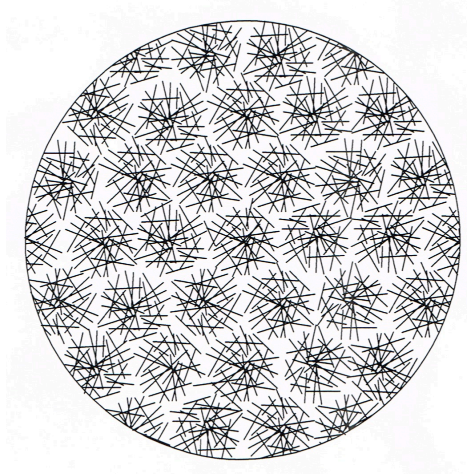

Figure 2: The *Mosaic of Live-Work Communities* Model.

In this model (see figure 2), Both people and workplaces are also highly mobile: people move as close as possible to their jobs, and workplaces move as close as possible to their employees, eliminating any wasteful commuting. When people lose or quit their job, they either find a new job in the community or move to a new community where their new job is located, so as to remain within walking and bicycling distance to work. When a workplace changes its location, its workforce relocates to the new location as well or is replaced by a new workforce in the new location. The attraction between residents of such live-work communities may or may not be strong, but these communities can become stable over time—allowing their residents sufficient time to build trust and accumulate social capital—if their residents can find permanent employment in the community, in one job or another, and do not seek more lucrative or more challenging employment in the larger metropolitan labor market. They must also be willing and able to perform *all* the required jobs in the community without importing workers from other communities. In an important sense, this model was the underlying spatial structure of the ideal city proposed by Ebenezer Howard, the inventor of the self-contained suburb as the antidote to the intolerable living and working conditions in the nineteenth-century industrial cities, in his *Garden Cities of Tomorrow* (1899). And this was the hope of the visionary British planners who built the new towns on the periphery of large cities in the 1940s, 1950s, and 1960s with the expectation that they too would be self-contained live-work communities.

The third model is the *Monocentric City* model. In this model, all workplaces congregate in a single location in close proximity to each other and possibly in close proximity to a feature of the landscape, a port, a mine, a holy place, or a transport hub. When they do all congregate together, the cost of shipping goods and exchanging services between them is reduced. They can specialize and offer each other a greater variety of products and services. They can enjoy economies of scale in the provision of public works and amenities. They can share risks and form partnerships. And they can benefit from the free exchange of knowledge and ideas and learn from each other. In other words, other things being equal, firms can be more productive when they all congregate at the city center, commonly referred to as the Central Business district (CBD).

Workers seeking to live in close proximity to their workplaces, locate their homes around the CBD. New homes, seeking to maximize access to the CBD, locate on the urban fringe as close as possible to the CBD, thus gradually forming a circle around it. More homes, again seeking to maximize access to the CBD, locate in a new ring just outside that circle, gradually creating in a circular city about its historical center. In other words, the shape of a city in which overall access to its center is maximized is a circle (Angel and Parent, 2011). At the same time, businesses seeking to maximize access to workers and consumers in this circular city will seek locations at its center. In a circle, the center is the most accessible place, namely the location with the shortest average distance to all other locations. In the absence of congestion, it is also the location with the shortest average time, and hence the lowest average cost as well, from all other locations. There is thus a theoretical rationale for cities to be circular and for their historical center to maintain its dominance as the preferred location for businesses seeking greater access to the city as a whole (see figure 3). We define the model as follows,

> *The Monocentric City* model: All jobs are concentrated in the Central Business District (CBD). All workers—living in concentric rings at greater and greater distances from the CBD—commute on radial routes to their jobs in the CBD.

The classical monocentric model of the city, posited by Alonso (1964), and later by Mills (1967) and Muth (1969), assumes *a priori* that all jobs must be concentrated at a singular point in the Central Business District (CBD); that all residences are arranged in circular rings around that point; and that workers commute along radial routes to their jobs at the CBD. The model was adopted from Von Thünen's model of *The Isolated State* (1826) to describe the emerging differentiation of land uses resulting from competition for land in an abstract circular state on a flat plain. In their model, workers maximize their utility by deciding how much to pay in land rent and how much in transport cost. Workers living closer to the center pay more for land and less for transport, and those living further away pay less for land and more for transport. Their model is able to show that workers living close to the center will consume less land than those living further away and thus that residential densities will decline with distance from the CBD. They are also able to show that at the urban edge, land rent will equal the surrounding agricultural rent. As income or population increase and as transport costs decline, the city will expand outwards. Conversely, as transport costs or agricultural rents increase, the city will shrink inwards.

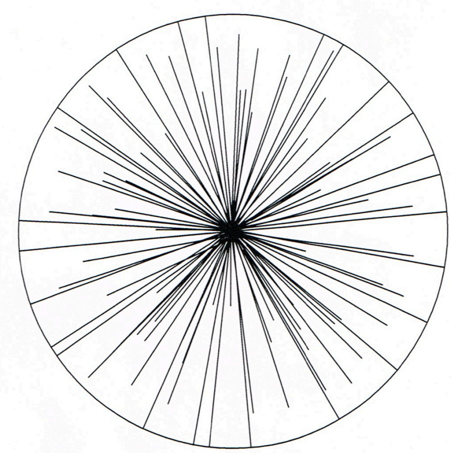

Figure 3: The *Monocentric City* Model.

A less rigid exposition of the monocentric city model does not require that all workplaces be concentrated *at a single point* in the city center, as assumed in its classical theoretical model, but that the Central Business district (CBD) have the largest concentration of workplaces in the city; that the density of jobs peak at the CBD and then decline with distance from the CBD; and that jobs be always more centralized that residences. Admittedly, though the monocentric city model is a very simple theoretical construct of urban spatial structure, Mills and Tan observe that "[t]here are few cases in economics in which such a simple theory leads to so many testable implications" (Mills and Tan 1980, 314).

The monocentric model gives precedence to the strong forces of attraction between workplaces, forces that bring them all together into one central location. Workers are compelled to locate their residences in close proximity to the center, but—because their residences occupy land—as the city grows out they must locate further and further away from their workplaces, incurring higher and higher transport costs. In this model, commuting costs at the center are zero or negligible, and average commuting costs increase with city size. There are forces separating poor and rich households: The poor must locate as close to the center as possible to save on transport cost—living at higher densities and occupying less land—while the rich can afford to live in larger houses at lower densities further away. But there are no forces repelling workplaces from one another, like competition for land at the city center that results in high land prices or competition for road space that results in congestion.

The fourth model is the *Polycentric City* model. In this model, workplaces are still pulled together by strong attractions, and they are all concentrated in a number of centers dispersed throughout the metropolitan area, not only in the CBD. In these centers—typically located around transportation hubs with good access to the metropolitan area as a whole—workplaces share local public goods as well as local amenities. They may also benefit from the ability to form partnerships and share a common pool of workers, and from the ability of their workers to share knowledge with each other. Because these centers are distributed in the entire metropolitan areas, they may be closer, on average, to the residences of some workers than the CBD. But, other things being equal, by leaving the center of the city—its most accessible location—they become less accessible to the metropolitan area as a whole. We define the model as follows,

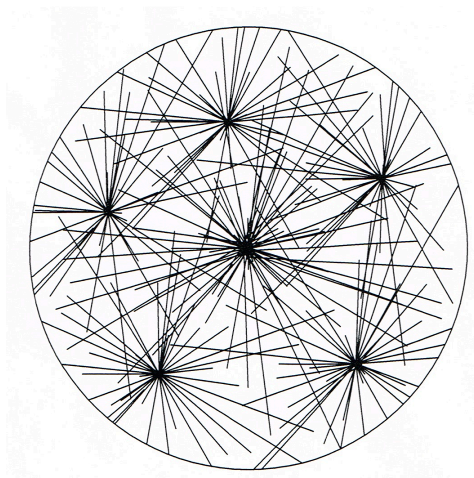

Figure 4: The *Polycentric City* Model.

> *The Polycentric City* model: Workers commute to a discrete set of identifiable employment sub-centers—including but not restricted to the CBD—located throughout the metropolitan area.

The theoretical rationale for all workplaces to concentrate at the city center breaks down on at least three counts. First, the city center, by definition, occupies a small amount of land and when a large number of workplaces compete for that land, its price increases. The high price of land in the city center compromises its access advantages, compelling firms, especially those that need large amounts of floor space (and ample parking space) to leave the center for other locations in the metropolitan area. These locations may be less accessible to the metropolitan area as a whole, but land and structures there will be more plentiful and less expensive. Second, competition for land in the city center also means that there is limited land available for roads carrying cars, busses and trolleys, and that when large numbers of workers commute to the center, the roads in and around the center become congested, increasing both the time and cost of commuting to the center and again compromising its access advantages. This also encourages firms to locate outside the city center so as to be more accessible to their workers. Third, the need to rehabilitate, rebuild and refurbish aging city centers as technology, production methods, land values, and cultural habits change is considerably more complex, more time consuming and more expensive than new construction in 'green fields' in peripheral locations, again pushing new or growing firms to locate in new sub-centers or 'edge cities' (Jarreau, 1991) in outlying areas. There are thus centrifugal forces that weaken the ties binding all workplaces together at the CBD and pull subsets of workplaces away from the city center and into employment sub-centers located throughout the metropolitan area (see figure 4).

The fifth and final model is the *Constrained Dispersal* model. This model takes into account both the weakening centripetal forces that held the majority of jobs together at the CBD in the Monocentric City model and the emerging inability of employment sub-centers in the Polycentric City model to attract the majority of jobs that have left the CBD. The majority of jobs disperse outside the CBD and outside employment sub-centers but the weak centripetal forces still acting to attract jobs to each other or to common infrastructure services and amenities constrain the *total* dispersal of jobs assumed in the Maximum Disorder model. This model postulates a single metropolitan labor market where individual workers locate within a tolerable commute distance to the best job they can find in this market (see figure 5). The desire to be within a tolerable commute distance of jobs also constraints the total dispersal of jobs and residences relative to each other assumed in the Maximum Disorder model. Yet workers do not try to minimize the length of their commute assumed in the Mosaic of Live-Work Communities model, and closeness to their job is only one of many considerations in their residential location decision. Other considerations include the desire to be near friends and family; near people of the same income, cultural, ethnic or religious background; near better schools; near concentrations of amenities; or in compromise locations that meet the need of two-worker households. Most workplaces, on their part, locate throughout the metropolitan area so as to be closer to workers and to reduce their land and building costs, and the forces attracting them to each other are altogether weak (see also Gordon and Richardson, 1993 and Lang, 2003), except for their need to share a large metropolitan labor market, and their occasional need to share local public goods such as common zoning, infrastructure, and amenities. We define the model as follows,

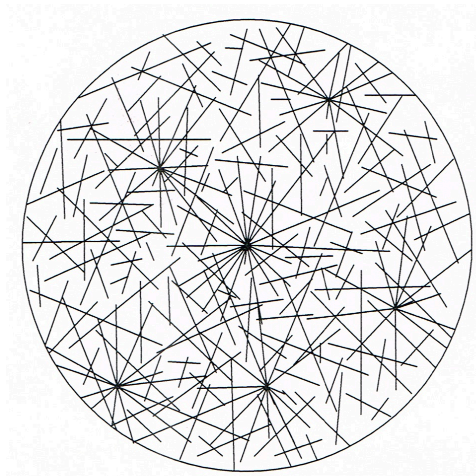

Figure 5: The *Constrained dispersal* Model.

> *The Constrained Dispersal* model: Outside the CBD and a small number of employment sub-centers that still attract workplaces to each other or to shared public infrastructure and amenities, the great majority of workplaces are dispersed throughout a single

metropolitan labor market, and both workers and workplaces adjust their locations so that they remain within a tolerable commuting range of each other.

From the perspective of the Constrained Dispersal model, the second critical flaw in the *Maximum Disorder* model is that it also assumes that distance no longer matters, thus ignoring the most basic raison d'être of cities: bringing people into closer proximity to each other and to a host of job opportunities. It is that need for closeness that had created metropolitan areas in the first place, and it is that need for closeness that gives their commuting patterns their spatial structure. These patterns must necessarily display the preference of workers to be within a tolerable commute time, and hence distance, from their jobs; and the preference of workplaces to be within a tolerable commute time, and hence distance, from their workers. That need for closeness does not imply that jobs and residences must be on top of each other or within walking distance of each other as assumed by the Mosaic of Live-Work Communities model. On the contrary, it only implies that they cannot allow themselves to be too far from each other regardless of the size of the metropolitan area. Thus this model is characterized by longer commute trips than those assumed by the Mosaic of Live-Work Communities model, but by shorter trips than those assumed by the Maximum Disorder model or by the Monocentric City model.

The Constrained Dispersal model is, in essence, a *hybrid* model that combines elements of all other models. It postulates that the Maximum Disorder model is largely correct, except that in applies only to the great majority of jobs but not to all jobs, and except that commuters and workplaces move to be within a tolerable commute distance of each other. It postulates that the Mosaic of Live-Work Communities model is also correct, except that it only applies to a small minority of people who live and work in the same community. It postulates that the Monocentric City model is also correct, except that only a small minority of jobs rather than all jobs still locate at the CBD. And it postulates that the Polycentric City model is also correct, except that only a small minority of jobs rather than all jobs locate in the CBD and in employment sub-centers. In general, it postulates that the total dispersal postulated by the Maximum Disorder model is constrained by weak, yet effective, attractive forces that bring residences and workplaces closer to each other and by weak, yet effective, attractive forces that brings workplaces closer to other workplaces.

In the following section of this paper we present statistical evidence from the cities we studied that may help us decide which one of these models better fits the observed spatial realities of contemporary American cities.

II The Evidence

The evidence presented here is based on two data sets. The first dataset comprises census-based geographic information on the origins (residences) and destinations (workplaces) of commuters in the urbanized areas of a stratified sample of 40 U.S. cities and metropolitan areas in 2000. The urbanized areas, as we shall see, roughly correspond to the built-up areas of cities. The second dataset comprises geographic information on the share of destinations (workplaces) in sub-centers, including the Central Business District (CBD), in the 50 largest U.S. cities and metropolitan areas in the year 2000, calculated from data obtained from Lee. Details regarding these two data sets are given in the two Annexes to this paper.

1. Visual evidence from a random set of 200 origin and destinations pairs in six cities

As the first piece of evidence, we present a set of maps of the urbanized areas of six cities in 2000—Los Angeles, Philadelphia, Atlanta, Boston, Chicago and Houston. Maps of the remaining 34 cities in our sample are visually similar and have been omitted for lack of space. Each of the six maps shows a random sample of 200 commutes within the city's urbanized area, represented by straight lines describing the beeline path between an origin and a destination. Destinations are shown as small black dots at one end of the beeline path. Origin and destination pairs that begin and end in the same census tract are shown as small red triangles. The sample is admittedly small. In Atlanta, for example, there were 1.89 million commutes in 2000 so the sample consists of only 0.01% of the total number of commutes. We could only display such small a sample of commutes because we found by repeated experimentation that larger numbers of lines simply fill the urbanized area and obscure their underlying patterns. That said, even that small sample is statistically representative. To test whether the sample is indeed representative, we compared the mean trip distance (in its logarithmic form, which more closely approximates the Normal Distribution) in the 200-commutes sample and in the universe of all commutes in Atlanta. The means are not statistically different at the 95% confidence level. We repeated the test and obtained the same results for the remaining five cities. The results suggest that the patterns displayed by the random sample of origin and destination pairs in the selected cities correctly represent the overall patterns of all commuter trips in the selected cities. The maps for the six selected cities are shown in figure 6.

We can now compare these maps to the five models of the spatial structure of cities presented earlier. The comparisons are only visual comparisons rather than statistical ones, but sometimes a picture illustrates a point better than a statistic. Comparing these maps with the figures shown earlier, we can surmise (1) that these cities are not Mosaics of Live-Work Communities (trips crisscross the entire metropolitan area and most of them seem longer than walking or biking trips); (2) that they are not Monocentric (most trips do not have the Central Business District—the CBD—as their common destination); and (3) that they are not Polycentric (most trips do not have the CBD or any sub-center as their common destinations). Yet simply inspecting these maps, it is difficult to say whether they conform to the Maximum Disorder model or to the Constrained Dispersal model. In the former model, there is no CBD, of course. In a few of these cities—Chicago and Boston, and to a lesser extent Philadelphia and Atlanta—a number of commute trips do share the CBD as a common destination. Finally, trip length appear, on first inspection, to be shorter than those predicted by the Maximum Disorder model. This suggests that American cities may better conform to the Constrained Dispersal model rather than to the Maximum Disorder model, but the maps shown here are only suggestive in that regard. To better differentiate between these two models, we require the more substantial evidence presented below.

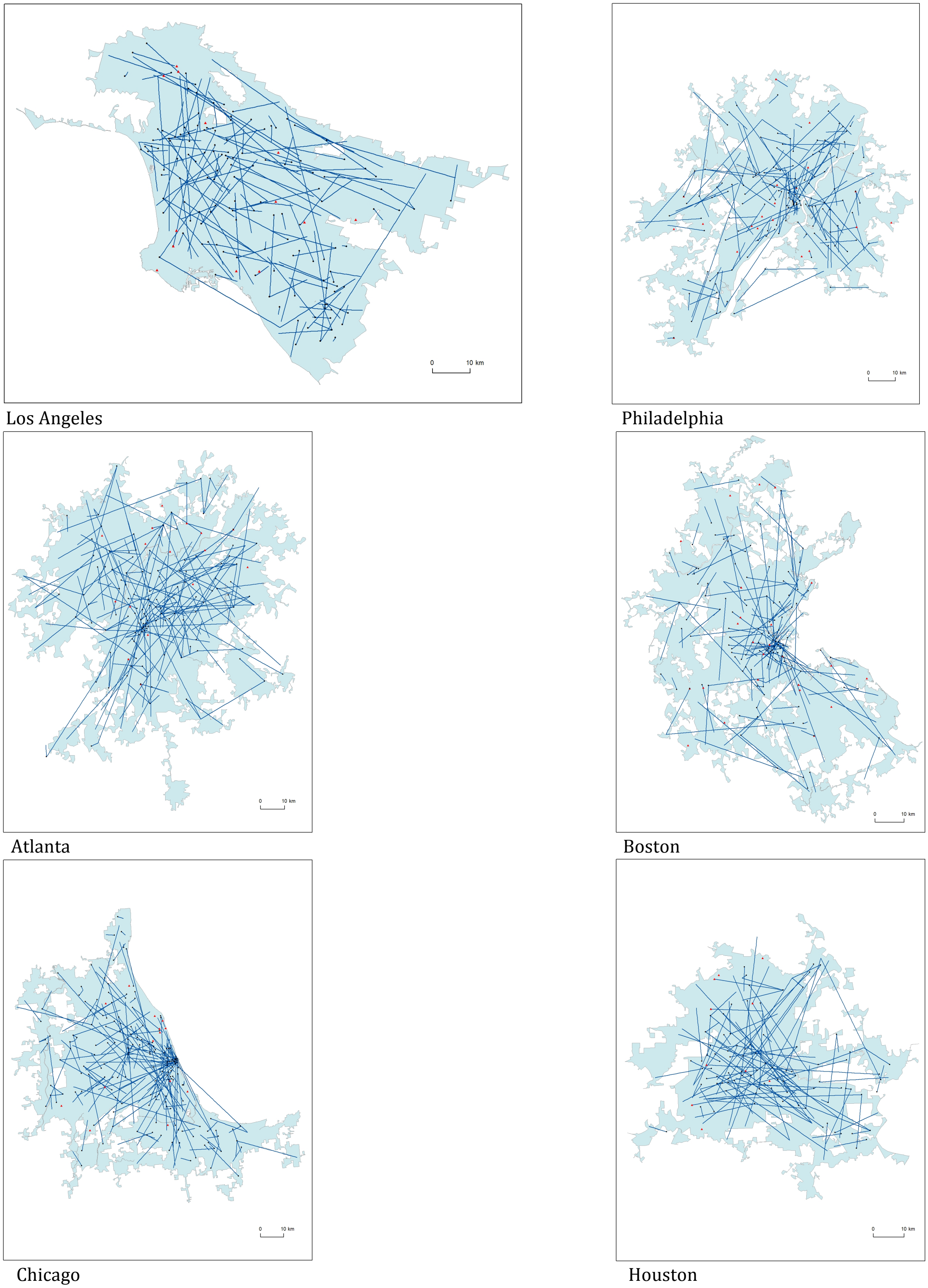

Figure 6: 200 randomly selected Origin-Destination commute pairs in six American cities, 2000

2. The existence of a tolerable commuting range

> [L]ess newsworthy are the actions of the modest proportions of commuters who each year change residence and/or work place to avoid congestion and reduce their commuting times. These unsung heroes of metropolitan travel behavior explain why commuting times in the largest cities remain stable or decline despite impressionistic, but probably reliable, evidence of increasing congestion along particular highway segments (Gordon and Richardson 1991, 419).

There is a considerable literature devoted to understanding the interdependence between residential location, job location, and commuting distance. A critical insight in this literature is that there is a *tolerable commute range*, a commuting radius, so to speak, within which workers are indifferent to their job location (Getis, 1969), as suggested by the Constrained Dispersal model of urban spatial structure. When people change jobs to locations outside their tolerable commute range, they are more likely to move to a new home closer to their job that those who change jobs to locations within it (Brown, 1975). As Clark, Huang and Withers note (2003, 201), "[s]imply, if a household is a long distance from the workplace, when the household moves, it is likely to move nearer the workplace". More generally, the longer the commuting distance, the higher the propensity to quit a job or to change residence (Zax and Kain, 1991). This is an important insight. It suggests that households have diverse reasons for moving from one location to another, and that moving closer to their workplace becomes critical only when the workplace is outside their tolerable commuting range. Data from the U.S. Census Bureau for *intra-county* residential moves in 2008-2009 indeed confirms that only 9 percent of all residential moves were for employment-related reasons; that 5 percent of all those residential moves were to be closer to an existing workplace or to have an easier commute to that workplace; and that 2.1 percent were to be closer to a new workplace (U.S. Census, 2011, table 7, 16).

Clark, Huang and Withers (2003) provide empirical evidence pertaining to households that have changed residences—with or without changing their jobs—in the Seattle, WA, area between 1989 and 1997. They find that

> In the aggregate more households, whether with one or two workers, reduced their commutes after moving. Analyzing the results by the pre-move commute reveals a distinct pattern in which households with longer commutes before the move almost always reduced their commuting distance and time. (206-207)

Their findings are summarized in figure 7. The graph in figure 7 contains information on 462 households—some with one worker and some with two workers—that changed their residence during the study period, some while changing their jobs and some while retaining their jobs. As a group, a minority of 42% increased the distance of their commute when they relocated their homes, while a majority of 58% chose new residential locations that were either closer or at the same distance to their workplaces. But as the graph shows, the majority of commuters who lived less than 8 miles from their workplace increased their commute distance when they moved. When their original distance to work was more than 16 miles, more than two-thirds of commuters moved to places that were closer to their jobs. And of those that originally lived more than 32 miles away from their jobs, 95% found new homes in locations closer to their workplaces. We can draw a more general conclusion from this graph: Most commuters do not move closer to their workplaces as long as their workplaces are within an tolerable commute range, but do move closer when their workplaces are outside their tolerable commute range. The fact that workers do not seek to minimize their commute distance should come as no surprise: They have other reasons to guide their residential (and job) moves and they want to cast their net far and wide to find satisfactory locations—be they for a home or for a workplace—subject to the constraint that, if at all possible, should not be beyond their tolerable commute range. Indeed, the overall productivity of metropolitan labor markets does not require that workers be as close to their workplaces as possible, only that they will be within an tolerable commute range of the best job they can find. And from the perspective of workers, that tolerable commute range should be quite generous because the larger and more varied the housing choices within their tolerable commute range of the best job they can find the better off they will be. It stands to reason that it is these locational adjustments that keep the great majority of the urban workforce within its tolerable commute range regardless of how large the metropolitan area may be. This implies that if the spatial structure of American cities conformed to the Constrained Dispersal model then actual commuting distances in American cities should be significantly smaller than those predicted by the Maximum Dispersal model. The evidence presented in the next section confirms that this is indeed the case.

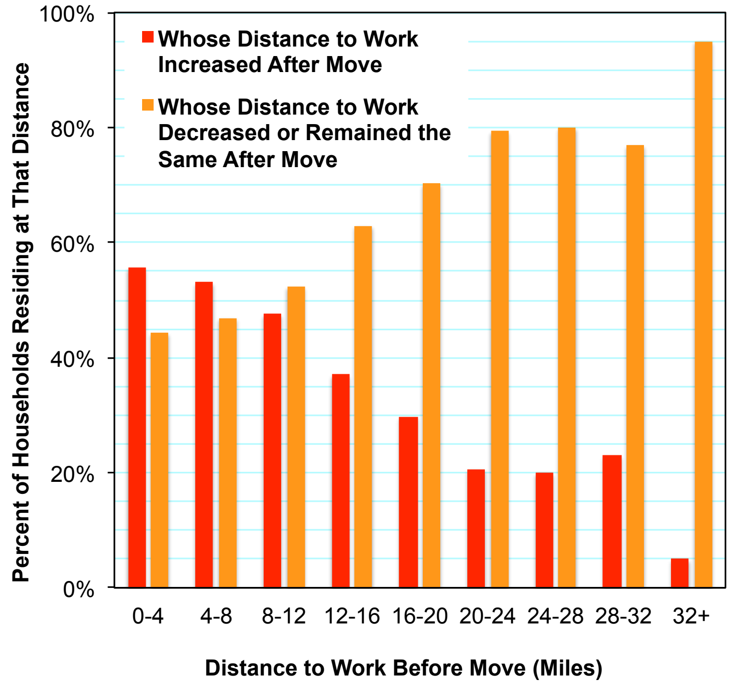

Figure 7: Changes in distance to work after residential moves for 462 households in the Seattle, WA, area, 1989-1997.

Source: Calculated from Clark, Huang and Withers, 2003, table 2, 207.

3. Actual versus expected average commute distances in the sample of cities

As a third piece of evidence, we present data from our first dataset which includes information on the origins and destinations of commuters by census tract in a stratified sample of 40 American cities, described in greater detail in Annex 1. Using these data, we calculated the weighted average beeline commute distance in each city in our sample of 40 American cities, as shown in the maps in figure 6 above. We then compared it with the expected average commute distance predicted by the models of urban spatial structure presented earlier. As we shall see in this section, each of the models implies a different average commute distance and only two of the models—the Polycentric City model and the Constrained Dispersal model predict average distances that are in the range of the actual average commute distances observed in the sample.

The Maximum disorder model, for example, postulates that commuters' residences and jobs are located at random throughout the urbanized area and that commuters travel from a random residence to a random job. We simulated that process in each of the 40 cities in the sample and—assuming that commuters travel in a straight line—calculated the beeline distances between a set of random point pairs throughout the metropolitan area. We then calculated the average beeline distance of these sets of random point pairs for each city. This average value for each city in the sample—the expected commute distance in the Maximum Disorder model—is displayed in figure 8 (a yellow circle) as a function of its urbanized area.[1]

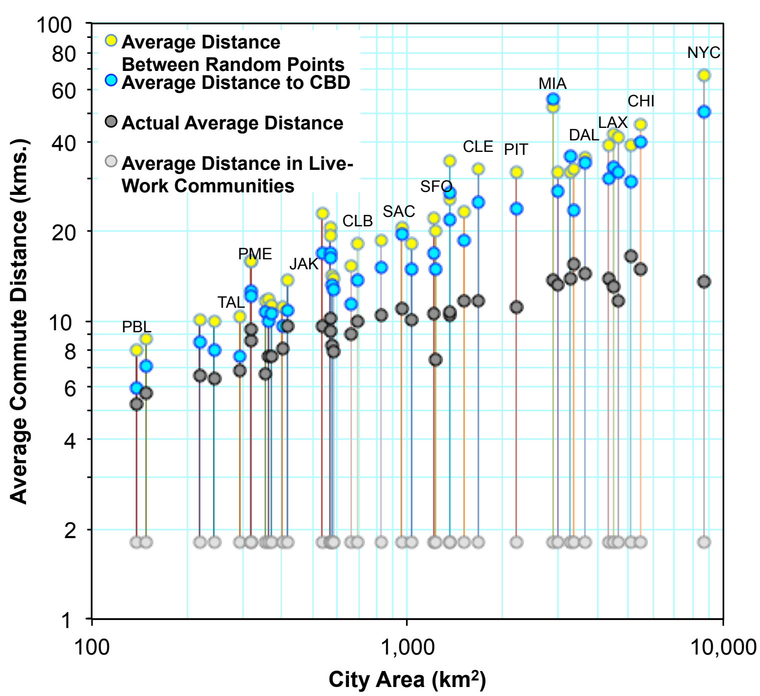

Figure 8: Theoretical and actual average commute distances in a sample of 40 U.S. cities in 2000

The Monocentric City model postulates that commuters' residences are located at random throughout the urbanized area and that all commuters travel from a random residence to their workplace in the CBD. We simulated that process in each of the 40 cities in the sample and—assuming that commuters travel in a straight line—calculated the beeline distances between a set of random points throughout the metropolitan area and the city center, assumed to be City Hall. We then calculated the average beeline distance of this set of points for each city. This average value for each city in the sample—

[1] This graph is drawn with logarithmic scales on both the *x*-axis and the *y*-axis.

the expected commute distance in the Monocentric City model—is displayed in figure 8 (a light blue circle) as a function of its urbanized area. That value for any given city falls on the same vertical line as the value for the Maximum Disorder model, of course, because its area remains the same. For 39 out of the 40 cities, the average distance to the city center is shorter than the average distance between two random points in the city. Miami (with an area close to 3,000 km^2) stands out as the only exception: the average distance to its city center, located at the southernmost edge of the metropolitan area, is greater than the average distance between two random points in the metropolitan area.

The Mosaic of Live-Work Communities model postulates that commuters' residences and workplaces are located within walking distance from each other and that people, by and large, walk to work. To err on the generous side, we postulated that a live-work community could be a circle with a radius as large as 2.0 kilometers. This radius roughly corresponds to the outer radius of an average American city CBD. As we shall show later, the average area of the CBD in 50 U.S. metropolitan areas in 2000 was 840 hectares or 8.4 km^2. If that area were a circle, its radius would be 1.5 kilometers. But since CBDs are not typically circular in shape, a circle encompassing an average size CBD could have a radius of the order of 2 kilometers.

It can be ascertained[2] that the average distance D between any two points in a circle is $0.9045R$, where R is the radius of the circle. Hence if R = 2 kilometers, D = 1.81 kilometers. Given our simplifying assumptions, the Mosaic of Live-Work Communities model thus postulates that the expected beeline commute distance in such communities would be 1.81 kilometers, and that it would be the same for all cities in the sample. This value for each city in the sample is displayed in figure 8 (a light grey circle) as a function of its urbanized area.

Figure 8 shows that actual beeline commute distances in our sample of 40 American cities are smaller than those predicted by the Maximum Disorder and the Monocentric City models and larger than those predicted by the Mosaic of Live-Work Communities model. In fact, we can say with 95% confidence that the average value of actual commute distance for all 40 cities in the sample is 10.3±0.9 kilometers. Similarly, we can say that the corresponding average value for the Maximum Disorder model is 24.5±4.6 kilometers and that the average value for the Monocentric City model is 20.1±3.8 kilometers. We also know that the maximum average value for the Mosaic of Live-Work Communities model is 1.8 kilometers. Given these findings, we can reject the hypotheses that the commute distances predicted by all three models are not statistically different from actual commute distances in our sample of cities with a 95% level of confidence. In other words, both the Maximum Disorder model and the Monocentric City model predict average commute distances that are significantly larger than those observed in the cities we studied, while the Mosaic of Live-Work Communities model predicts average commute distances that are significantly smaller than those observed.

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2 See Mathematics Stack Exchange online at http://math.stackexchange.com/questions/135766/average-distance-between-two-points-in-a-circular-disk.

Both the Polycentric City model and the Constrained Dispersal model assume that jobs decentralize, away from the CBD and into the rest of the urbanized area of the city. The Constrained Dispersal model further assumes that both commuter residences and workplaces relocate so as to remain within tolerable commute distances of each other. We cannot calculate what the average commuting distances predicted by these models would be, but we can assume that they would be smaller than those predicted by the Maximum Disorder and the Monocentric City models and larger than those predicted by the Mosaic of Live-Work Communities model. Given the actual commute distance data in our sample of cities, we cannot reject the hypotheses that the commute distances predicted by these two models are not statistically different from actual commute distances in our sample of cities.

To conclude, the third piece of evidence presented in this section leads us to reject three of the five models of urban spatial structure—the Maximum Disorder model, the Monocentric City model and the Mosaic of Live-Work Communities model—as faithful descriptions of the spatial structure of contemporary American cities. Given this evidence, however, we cannot reject the remaining two models—the Polycentric City model and the Constrained Dispersal model—as potentially faithful descriptions of the spatial structure of contemporary American cities.

Still, those who refuse to let go of the Monocentric City model may argue that our test assumed a very strict form of the Monocentric City model, namely that *all* jobs are concentrated at a point in the city center. This, they may argue, was never the case. Indeed, if CBDs did not contain all jobs but only *the great majority of jobs* and these jobs were scattered over a small area around the city center it may well be that the average distance to jobs would not be statistically different than the observed average distance, and therefore that a more relaxed form of the Monocentric City model may still be a relevant description of contemporary urban spatial structure. To confront this objection, we present a fourth piece of evidence that further disqualifies the Monocentric City model as a potentially faithful description of the spatial structure of contemporary American cities.

4. The share of jobs in the Central Business District

The Monocentric City model, in its purely theoretical form, indeed assumes that all jobs are located at a single point in the center of the city. This is, of course, an unrealistic assumption useful only for mathematical modeling of the city. A more relaxed assumption would be that the great majority of jobs—say more than half of all jobs in the city—are located in close proximity to each other in a small area around the city center, typically referred to in the literature as the Central Business District (CBD). Surely, this may have been true before the advent of the private automobile and the truck, but it is certainly no longer the case as many researchers, the world over, have already shown.[3] Yet the belief that most jobs, and hence most commute destinations, are located in the CBD persists among those who still see contemporary metropolitan areas as conforming to the Monocentric City model. High buildings and high land values at the city center, coupled with

[3] For a review of this literature, see Anas, Arnott, and Small (1998).

congestion on the roads leading to it during the morning commute, gives intuitive credence to this enduring belief.

Kenworthy and Laube (1999), for example, collected data on commuting patterns in 47 cities, 40 of which had one million people or more in 1990: 13 cities in the United States, 7 in Canada, 6 in Australia, 11 in Europe, and 10 in Asia.[4] They defined the Central Business District (CBD) in each city as “the area with the most significant employment concentration in the metropolitan area and was generally decided in consultation with authorities in each city” (35). They also defined the urbanized area of each city using land use maps and seeking to ensure “that all land that is predominantly urban in its use was included” (38). On average, the area of the CBD in 1990 constituted only 1.8±0.8 percent of the urbanized area of 39 cities in their study for which data was available (in the 13 U.S. cities in the study it was only 0.26±0.08 percent). The share of jobs in the CBD (in a subset of 29 of these cities where data was available) declined significantly[5] from 25.4 percent in 1960 to 21.2 in 1970; it declined significantly again (in a subset of 38 cities where data was available) from 21.5 percent in 1970 to 18.1 percent in 1980; and it declined significantly yet again (in a subset of 41 cities where data was available) from 18.0 percent in 1980 to 16.2 percent in 1990. The only city in the sample is which the share of jobs in the CBD increased during this period was Tokyo, where it increased from 25.8 percent in 1960, to 26.1 percent in 1970, to 26.6 percent in 1980 and to 27.7 percent in 1990. On the whole, these data strongly suggest that Central Business Districts—loosely defined as the largest concentrations of workplaces—in cities and metropolitan areas the world over may now contain not more than one-fifth of the total jobs in these cities and metropolitan areas.

More recent and more comprehensive evidence on the share of jobs in the CBD in American cities is available from our second dataset, the dataset obtained from Professor Bumsoo Lee, which includes data on commuting patterns to the CBD and to other employment sub-centers in the 50 largest U.S. metropolitan areas in the year 2000. This dataset is described in detail in Annex 2 to this paper.

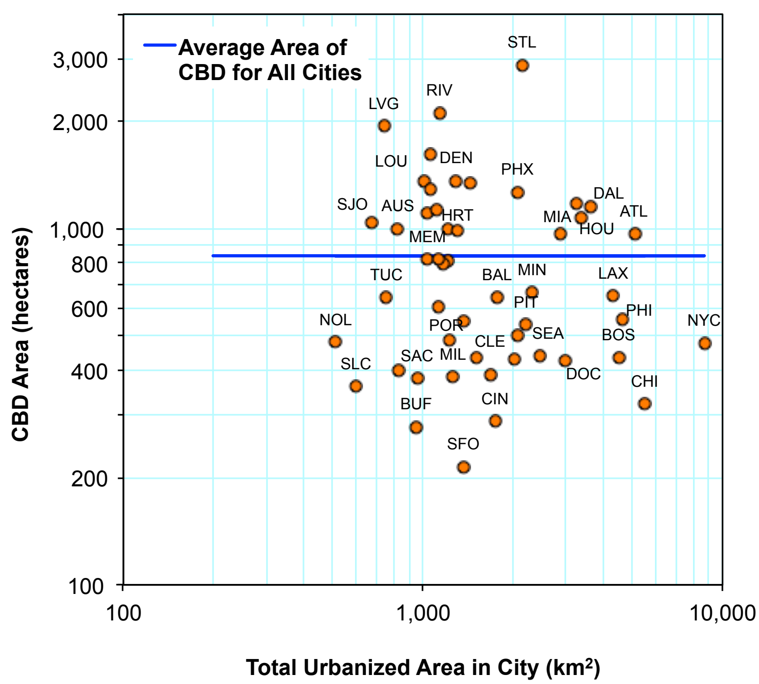

Figure 9: The areas of CBDs in the 50 largest U.S. Metropolitan Areas in 2000.

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[4] The discussion in this paragraph paraphrases Angel (2012), 196-97.

[5] The result of a statistical *t*-test of paired sample for means.

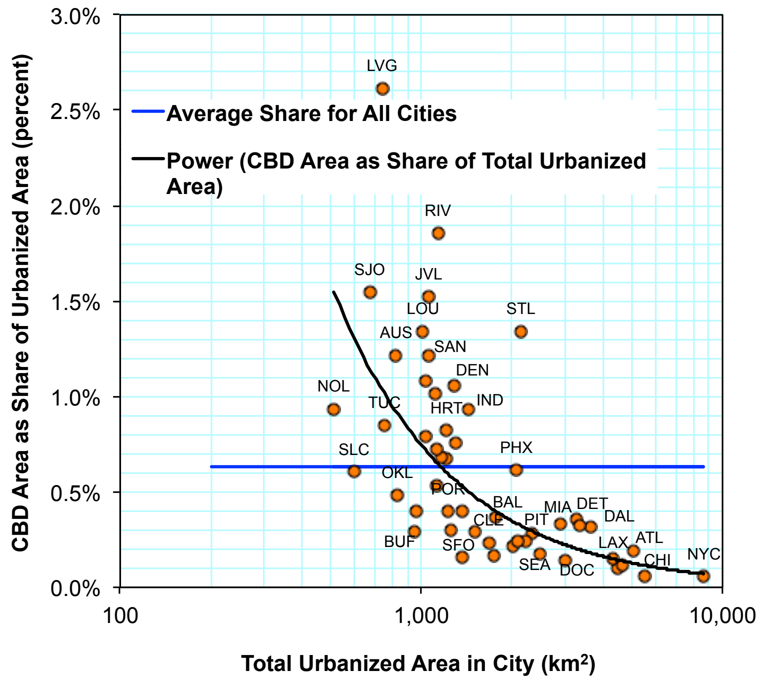

Figure 10: The areas of CBDs in the 50 largest U.S. Metropolitan Areas in 2000.

Central Business Districts (CBDs) in American cities were generally found to be quite small in size. In the largest 50 metropolitan areas in the U.S. in 2000, the average area of the CBD was 840±150 hectares and it varied from a maximum of 2,880 hectares in St. Louis, Missouri, to a minimum of 214 hectares in San Francisco, California. The area of the CBD was found to be independent of the size of the metropolitan area: Larger cities did not have either larger or smaller CBDs. This can be clearly observed in figure 9. The areas of CBDs as shares of the urbanized areas of American cities are shown in figure 10. As expected, that share declined systematically with the size of urbanized areas, from more than 1% in small cities to 0.1% in large ones. For a city double in area, that share declined to 47% of that of the smaller city and that decline was statistically significant ($R^2 = 0.59$).[6] The average share was 0.6% for the sample as a whole, more than double the value estimated by Kenworthy and Laube for 13 U.S. cities in 1990, but only one-third the average value of all the cities in their study.

What is the share of all commuter trips with origins and destinations within the urbanized area of American cities that have the CBD as their destination? We can answer this question by examining figure 11. Eleven smaller cities have a larger share of their total commute destinations in the CBD—greater than, say, 14 percent—but the relationship between the size of the metropolitan job market and the share of commuter destinations in the CBD is not statistically significant.

The average share of jobs that was located in the CBD for the 50 largest metropolitan areas in the U.S. in the year 2000 was 10.8±3.1%. It varied from a maximum of 21% in Austin, Texas, and Las Vegas, Nevada, to a minimum of 4% in Los Angeles, California. The median value for the 50 cities was 10%, and no city with more than one million jobs had more than 13% of these jobs in the CBD.

6 The power function shown in figure 10 for the CBD area, A_C, as a share of the city area, A, is $A_C = 14.405A^{-1.096}$ *(R =0.59)*, so that $A_C(2A) = 0.47A_C(A)$.

Given this overwhelming evidence, we must therefore conclude that the Monocentric City model is not an appropriate model for describing the overall spatial structure of contemporary American cities. Yes, the CBD is indeed the largest concentration of jobs in all American metropolitan areas. But this is a far cry from claiming that the great majority of jobs or, at the very least half the jobs, is located in the CBD and that therefore most commuting takes places from the rest of the city to the CBD. The evidence shows that only a small share of jobs—of the order of one-tenth of all jobs, on average, in American metropolitan areas in 2000—now remain in the CBD. Given this evidence, we must conclude that the Monocentric City model no longer captures the essence of urban spatial structure in American cities. It is, at best, a description of a small, not to say a marginal, share of commuting behavior in these cities. Needless to say, policies, programs and projects that focus the bulk of political and financial capital on this marginal share will not benefit the great majority of commuters—possibly as many as 90 percent of them, on average—that do not share the CBD as their destination.

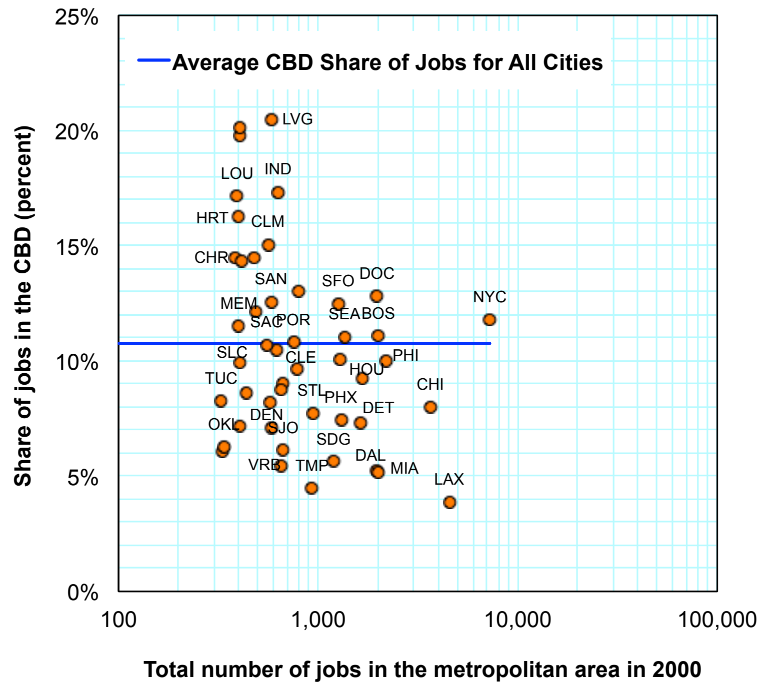

Figure 11: The share of jobs in the 50 largest U.S. metropolitan areas that was located in their CBDs in 2000.

5. The share of jobs in sub-centers outside the Central Business District

Even if workplaces are not concentrated in the CBD, there are still good economic reasons for workplaces to be in close proximity to each other and to form clusters. Duranton (2011, 9) summarizes these reasons:

> First, a larger market allows for more efficient *sharing* of indivisible facilities (e.g. local infrastructure), risks, and gains from variety and specialization.... Second, a larger market also allows for a better *matching* between employers and employees, buyers and suppliers, partners in joint-projects, or entrepreneurs and financiers.... Finally, a larger market can also facilitate *learning* about new technologies, market evolutions, or new forms of organization. More frequent direct interactions between economic agents in a cluster can thus favor the creation, diffusion and accumulation of knowledge.

While there is no reason to question the existence of agglomeration economies in cities, there is good reason to question the degree of proximity that is required for them to yield their expected benefits: Do businesses seeking to enjoy the benefits of proximity need to locate in employment centers or do they simply need to locate in the same metropolitan area? If the former is true, then we should expect to see significant clustering of workplaces in employment centers. If the latter is true, then we should expect to see significant de-clustering of businesses and their dispersal throughout metropolitan areas. Evidence on the share of jobs in employment sub-centers, including the CBD, should help us decide whether agglomeration economies require the closer proximity offered in employment sub-centers or whether they are features of the metropolitan area as a whole, as already suspected by some scholars (e.g. Gordon and Richardson, 1996).

The Polycentric City model in its pure theoretical form, assumes that *all* jobs are located in a finite set of employment centers—including the Central Business district (CBD)—scattered throughout the metropolitan area. As in the case of the Monocentric City model, this is again an unrealistic assumption useful only for mathematical modeling of the city. A more relaxed assumption would be that *the great majority of jobs*—say more than half of all jobs in the city—are located in well-defined employment centers. If that were true, then the Polycentric City model would capture the essence of the overall spatial structure of contemporary American cities.

Large American metropolitan areas are often conurbations, formed of a number of cities—large and small—that have gradually expanded towards each other so that they now form one contiguous urban expanse. Many of these cities retained their historical downtowns—often well connected to the regional transportation network—as concentrations of workplaces. It should not come as a surprise, therefore, that large metropolitan areas still contain numerous downtowns outside their Central Business District (CBD). The San Francisco Bay Area, for example, contains at least one dozen cities with populations of 100,000 people or more, each with its own employment sub-center. We can refer to those as *secondary downtowns*.

In addition, the movement of jobs away from Central Business Districts since the mid-1960s, has resulted in the creation of new employment sub-centers, referred to as *Edge Cities*, a term coined by Jarreau in a book by the same name published in 1991. Edge cities are new cities on the metropolitan periphery, not simply expansions of the existing historical cores of cities outside the central city. They are complete ‘cities’ in the sense of offering jobs, residences, and a full complement of shopping facilities, services, and amenities. And they are *top down* cities, cities that were created by the actions of a single large-scale developer, to be distinguished from *bottom up* cities that have emerged from the cumulative actions of a multitude of individual firms and households coming together over time. The developer selects a location with good transportation access to the CBD and to other important destinations; assembles the land; plans the city, usually with the car rather than the pedestrian in mind; obtains the necessary zoning, land use and subdivision and construction permits; invests in infrastructure; oversees the construction of office buildings, homes, shopping facilities, and amenities, all surrounded by ample parking; and sells or leases properties to interested parties, all the while retaining strict control of the development process. Municipal or state authorities may be partners in such ventures and, in some cases, even act as developers: "What is of the essence, however, is that all edge cities were originally the product of decisions by a single large agent; certainly we have uncovered no counter-examples of edge cities created purely through the decisions of atomistic agents" (Henderson and Mitra, 1996, 616). Henderson and Mitra (1996, 616) provide a list 9 edge cities—containing only 3 of the 10 largest ones identified by Jarreau—that, as of 1993, created, on average, 14 million square feet of office space each and employed, on average, 65,000 people each. These are large numbers: "As a reference point, cities such as Richmond, Spokane, Memphis, Wichita, Birmingham, Albany, and Little Rock have less than 5 million square feet of office space" (617), the threshold that Jarreau assumed for a concentration of workplaces in a metropolitan area to qualify as an edge city.

A large body of urban economic literature has attempted to define employment centers in U.S. metropolitan areas, to identify them, to count them, and to estimate the number of jobs they contain. A recent review of the literature (Giuliano, Agrawal and Redfearn, 2008) lists a large number of studies that have identified employment centers in a great number of American cities during the last two decades. One of the most rigorous is the one undertaken by Lee (see, e.g., Lee 2007). We have obtained the original dataset used in Lee and Lee (2014) from Professor Lee and used it to identify and analyze employment centers in the 50 largest American cities in 2000. The methods used by Lee and Lee to identify those employment centers is explained in detail in Annex 2 to this paper.

The Lee dataset distinguishes between the Central Business District (CBD) and other employment sub-centers, but does not distinguish between secondary downtowns and edge cities. For the purpose of this section, we group the latter two categories together, referring to them as employment sub-centers or, more generally as sub-centers, to distinguish them from the CBD. We seek answers to the following questions: (1) How many sub-centers—in addition to the CBD—are there in each of the 50 cities? (2) What is the average area of a sub-center in each City? (3) What is the share of all jobs in the city in employment sub-centers? and (4) What is the share of all jobs in the city in employment centers including the CBD? The answer to that fourth question is the evidence we seek

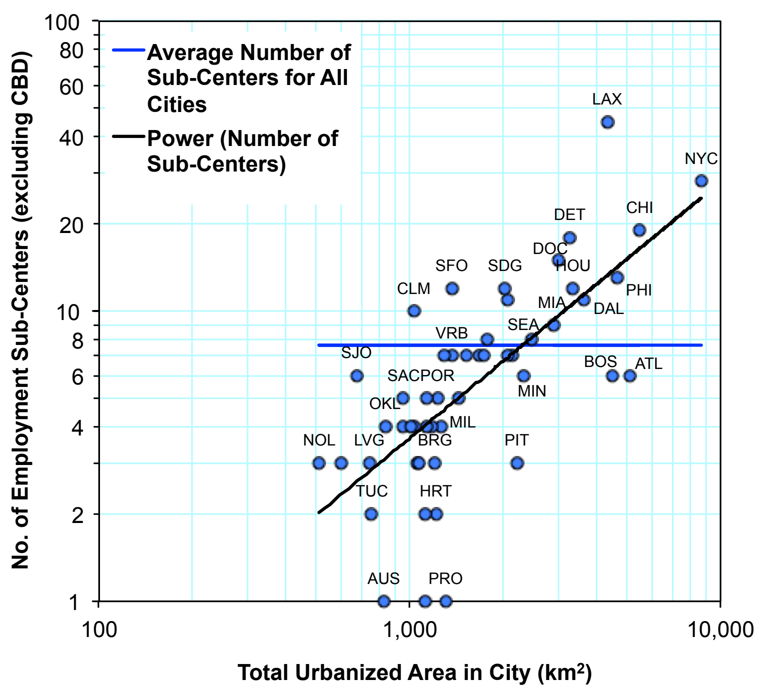

Figure 12: Number of employment sub-centers excluding the CBD (in the 50 largest U.S. metropolitan areas in 2000

in order to determine whether the Polycentric City model is an appropriate model for describing the overall spatial structure of contemporary American cities.

Large American cities with populations of 700,000 or more typically contain one of more employment sub-centers in addition to their Central Business District. On average, the 50 largest American cities contained 8±2 sub-centers in the year 2000, and the larger the city the more sub-centers it contained: In general, a city with double the area of a smaller one contained 1.84 times more sub-centers (see figure 12).[7] The increase in the number of centers both with the area of the city and with its total number of jobs was statistically significant (R^2 = 0.50). The number of sub-centers varied from a minimum of one in Austin, Texas, Nashville, Tennessee, and Providence, Rhode Island to 45 in Los Angeles, California.

Employment sub-centers in American cities are generally quite small in size. In the largest 50 metropolitan areas in the U.S. in 2000, the average area of the an employment sub-center was 1,280±260 hectares and it varied from a maximum of 6,357 hectares in Tucson, Arizona, to a minimum of 235 hectares in Providence, Rhode Island. It is important to note that the average area of employment sub-centers in the 50 cities studied was significantly larger than the average area of CBDs—1,280±260 hectares as against 840±150 hectares—at the 95% confidence level. As in the case of CBDs, the average area of sub-centers in a given city was found to be independent of the size of the metropolitan area: Employment sub-centers in larger cities did not have either larger or smaller average areas. This can be clearly observed in figure 13.

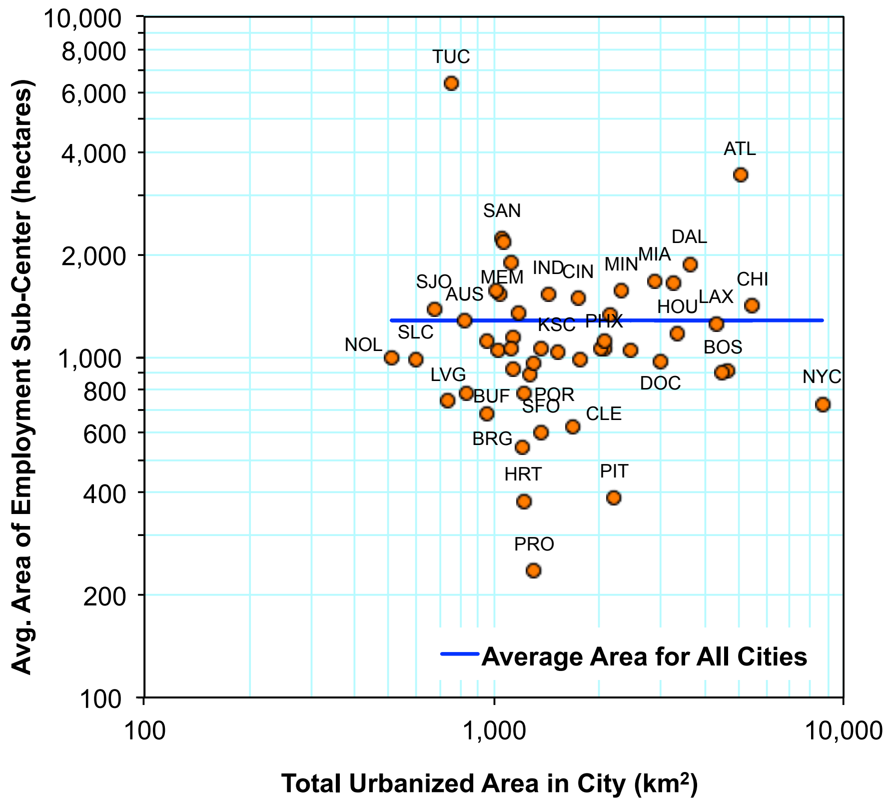

Figure 13: The average areas of employment sub-centers excluding the CBD in the 50 largest U.S. metropolitan areas in 2000

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7 The power function shown in figure 12 for the number of employment sub-centers, N_S, as a function of the urbanized area of the city, A, is $N_S = 0.0082A^{0.88}$ *(R =0.50)*, so that $N_S(2A) = 1.84N_S(A)$.

What is the share of all commuter trips with origins and destinations within the urbanized areas of American cities that have employment sub-centers, excluding the CBD, as their destination? We can answer this question by examining figure 14.

The average share of jobs that was located in employment sub-centers outside the CBD for the 50 largest metropolitan areas in the U.S. in the year 2000 was 13.8±2.0%. It varied from a maximum of 34% in Los Angeles, California, to a minimum of 2% in Providence, Rhode Island. The median value for the 50 cities was 12.8%, and 8 cities other than Los Angeles had more than 20% of their jobs in employment sub-centers: Columbus, Ohio; Detroit, Michigan; Dallas, Houston, and San Antonio, Texas; Tucson, Arizona; and San José and San Diego, California. 13 cities had less than 10% of jobs in employment sub-centers. The relationship between the size of the metropolitan job market and the share of commuter destinations in employment sub-centers was again found to be statistically insignificant.

We can now pose the central question of this section: What is the share of all commuter trips with origins and destinations within the urbanized areas of American cities that have employment centers, including the CBD, as their destination? We can answer this question by examining figure 15. In this figure, we simply added the values shown earlier in figure 11 to the values in figure 14.

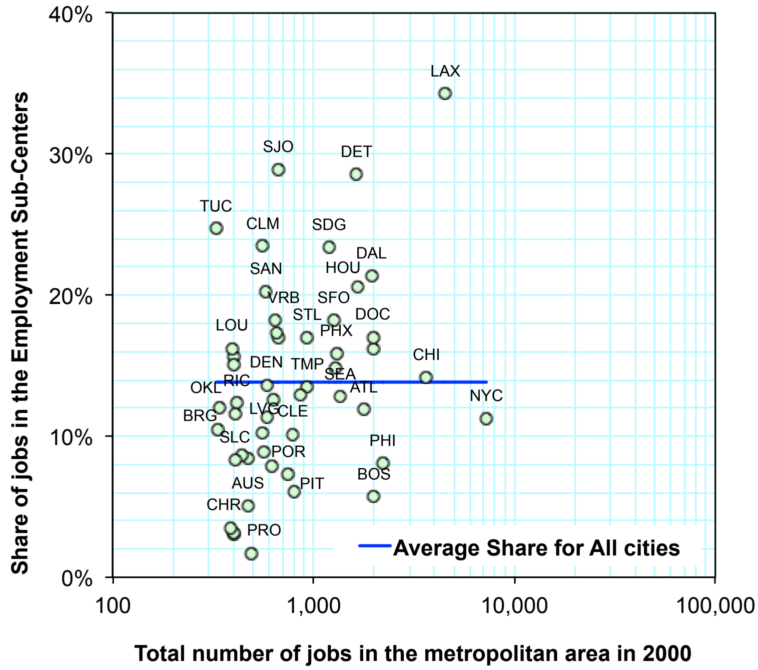

Figure 14: The share of jobs in employment sub-centers excluding the CBD in the 50 largest U.S. metropolitan areas in 2000

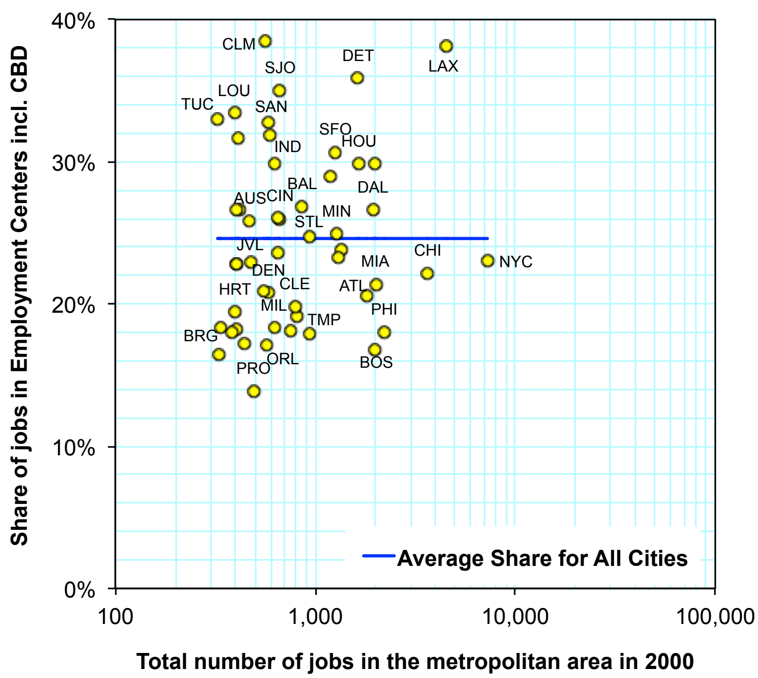

Figure 15: The share of jobs in employment sub-centers including the CBD in the 50 largest U.S. metropolitan areas in 2000

The average share of jobs that was located in employment centers including the CBD for the 50 largest metropolitan areas in the U.S. in the year 2000 was 24.6±1.8%. It varied from a maximum of 38.5% in Los Angeles, California, to a minimum of 13.9% in Providence, Rhode Island. The median value for the 50 cities was 23.5%, and 9 cities other than Los Angeles had more than 30% of their jobs in employment centers including the CBD: Columbus, Ohio; Detroit, Michigan; Dallas, Houston, and San Antonio, Texas; Tucson, Arizona; and San José and San Diego, California. The New York metropolitan area, the largest metropolitan area in the United States, had only 23% of its jobs in employment sub-centers including its CBD. Fifteen cities had less than 20% of their jobs in employment centers including the CBD. The relationship between the size of the metropolitan job market and the share of commuter destinations in employment sub-centers was again found to be statistically insignificant.

On average, therefore, only one-quarter of jobs in contemporary American metropolitan areas are located in employment sub-centers including the Central Business district (CBD), and in no city does this share exceed 40 percent. In other words, the great majority of jobs—three quarters of them, on average, are located outside employment centers, scattered throughout metropolitan areas. This suggests that the Polycentric City model—while certainly an improvement over the Monocentric City model—is still not a plausible description of the overall spatial structure of contemporary American Cities. The Constrained Dispersal model—the model that assumes that only a small share of jobs remain in employment centers, bound by weak attractive forces—appears to be a more appropriate model for describing urban spatial structure.

The evidence presented here also confirms the thesis advanced by Gordon and Richardson (1996): Agglomeration economies in American cities are largely properties of entire metropolitan areas than of smaller clusters within these metropolitan areas. One may ask, however, what about Silicon Valley, that heavy concentration of software establishments in a small part of the San Francisco Bay Area? Is not that an example of clustering at the sub-metropolitan level? The map in figure 16 shows the location of computer programming and software establishments in the San Francisco Bay Area in 2013.[8]

This map shows that programming and software establishments are not clustered at all. Surely, there is a small, dense cluster in the San Francisco Central Business District (CBD) and a denser distribution of firms in the San José metropolitan area and along the western edge of the San Francisco Peninsula, north and south of Palo Alto. There is also a denser concentration of establishments in Berkeley and Oakland in the East Bay. All in all, however, we must conclude that while software establishments in the United States may indeed be clustered in the San Francisco

[8] Custom computer programming services establishments in the North America Industry Classification System (NAICS) code 541511 include: Applications software programming services, custom computer; Computer program or software development, custom; Computer programming services, custom; Computer software analysis and design services, custom; Computer software programming services, custom; Computer software support services, custom; Programming services, custom computer; Software analysis and design services, custom computer; Software programming services, custom computer; and Web (i.e., Internet) page design services, custom.

Bay Area, they are not found in dense employment sub-centers there but are dispersed over very large areas throughout the metropolitan region.

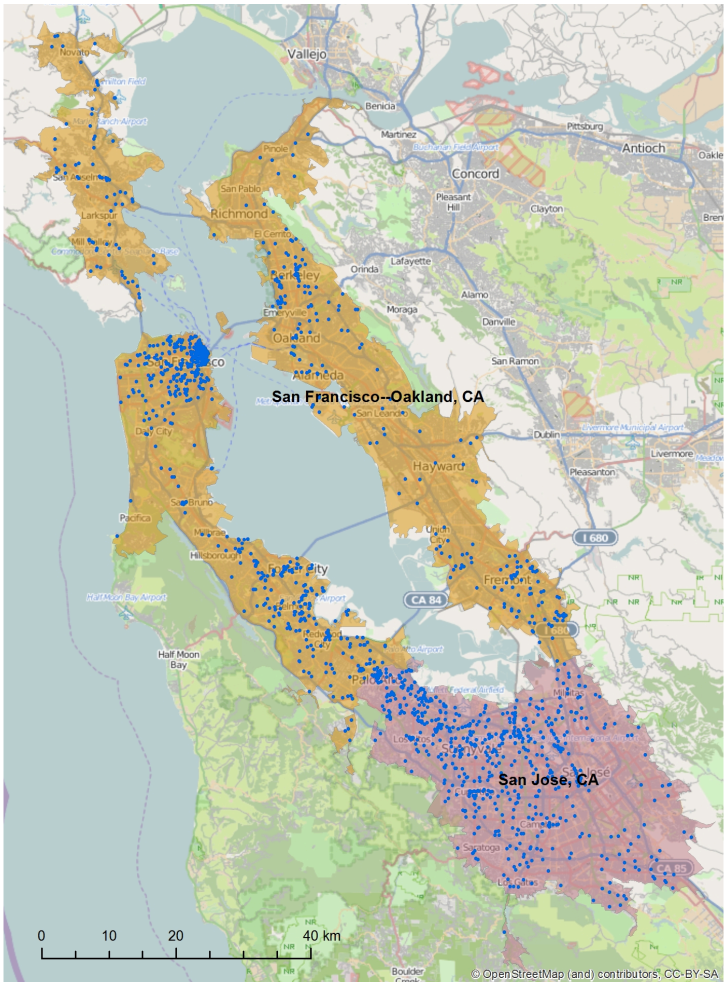

Figure 16: The location of all software establishments in the San Francisco Bay Area, 2013 (Geographic Research, Inc., 2014) .

In general, given this evidence we may conclude that employment sub-centers have failed to attract the large majority of jobs that had migrated out of Central Business Districts over the years, allowing workplaces to disperse everywhere to form large, unified metropolitan labor markets. The Polycentric City model thus fails to provide a viable description of American metropolitan areas at the present time. Clearly then, policies, programs and projects that take that model for granted and focus the bulk of political and financial capital on employment centers, say on connecting employment centers to each other by fixed-rail rapid transit, will not benefit the great majority of commuters—as many as 75 percent of them, on average—that do not share these employment centers, including the CBD, as their destinations.

6. The share of commuters who live and work in the same community

The sixth and last piece of evidence introduced in this paper pertains to the validity of the Mosaic of Live-Work Communities model as a useful description of the spatial structure of contemporary American cities. This model, in its pure and ideal form, views metropolitan areas as a set of small, discrete and self-contained economies, so to speak, with all commuting trips taking place within them and no commuting trips taking place between them. In contrast to all other models of urban spatial structure discussed in this paper, this model assumes that the different types of agglomeration economies in large cities that give them a productive advantage over smaller ones—and, more particularly, “a larger market [that] also allows for a better *matching* between employers and employees, buyers and suppliers, partners in joint-projects, or entrepreneurs and financiers”

(Duranton 2011, 9)—can all be internalized in small live-work communities. This model requires, therefore, that when residents of a metropolitan area change jobs they move to the communities that contain their new workplaces; that when people move to homes in a new community they find new jobs in that community; and that, as a result, every community has a job for every working resident and a residence for every worker and no more. If that were possible, then all excess commuting would be eliminated, everyone could walk or bicycle to work, and there would be no rush-hour congestion.

As noted earlier, this Mosaic of Live-Work Communities was the ideal form of the modern metropolis championed by Ebenezer Howard in *Garden Cities of Tomorrow* (1899), and all British new towns of the 1940s and 1950s were designed with that ideal in mind:

> Some of the most important ideas in the creation of the new towns are expressed in the goal that they should be 'self contained and balanced communities for working and living'…. There would be adequate employment in sufficient variety to make long journeys to work unnecessary…. In accordance with the aims of their planners, London's new towns have indeed become 'self-contained and balanced communities'…. At the level of analysis conducted in this study, London's new towns are a howling success (Thomas 1969, 381-382 and 448).

An early endorsement of self-contained communities in the U.S. was given by President Lyndon B. Johnson in his Message on Housing and Cities to the 90th Congress (February 1968, quoted in Alonso 1970, 38):

> But there is another way as well, which we should encourage and support. It is the new community, freshly planned and built…. The concept of new community is that of a balanced and beautiful community—not only a place to live, but a place to work as well. It will be largely self-contained, with light industry, shops, schools, hospitals, homes, apartments, and open spaces.

Alonso, in a comprehensive and devastating critique of self-contained communities that refers to this quote by President Johnson, concluded that

> [S]eeking closure at a small scale may economise on certain inputs (such as those of commuting) but results in lower per capita production (and lower disposable income after accounting for commuting costs) as well as the risks of instability and low adaptability which affect small cities. In small cities a declining firm can be a local disaster, new firms are less likely to develop because of the sparseness of linkages, a dismissed worker has fewer chances for re-employment, a boy has fewer career opportunities, a woman fewer choices for shopping, and so on. In short, trying to save on transport costs may be penny-wise and pound-foolish (Alonso, 1970, 44)

A recent article in the *Economist* reached a similar conclusion: "the lesson of the new towns is that being linked into a bigger city fosters growth…. The notion that they would be self-contained economies has largely failed" ("Paradise Lost", *The Economist*, 3 august 2013). This newer lesson confirms that Greater London, as expected, benefits from metropolitan-wide agglomeration economies that cannot be captured in self-contained live-work communities. It also suggests that new towns, in order to survive economically, are now less self-contained than they were in earlier decades when Thomas conducted his study. Whether this assertion is true or not requires the measurement of the degree of self-containment, a task that Thomas took upon himself in his analysis of British new towns in 1969.

Thomas defined an *Index of Commuting Independence* as the ratio of commuting trips originating and terminating in the new town ("local journeys") and the sum of both commuting trips originating elsewhere and terminating in the town and commuting trips originating in the town and terminating elsewhere ("crossing journeys"), so that "[t]he higher the value of the index, the more self-contained the town"(Thomas 1969, 393). He then proceeds to provide values for the index for eight new towns for 1951, 1961 and 1966. On average, the index increased from 0.85 to 1.33 between 1951 and 1961 and remained at that level in 1966 (Thomas 1969, table 4, 393). In other words, in the early 1960s local journeys exceeded crossing journeys by one-third, on average, allowing him to conclude that in terms of self-containment "London's new towns are a howling success" (Thomas 1969, 448).

Thomas's index attains the value of infinity when all trips originate and terminate within the community, and it is possible to improve upon his index by ensuring that it varies only from 0 to 1, attaining the value of 0 when no one both lives and works in the community and the value of 1 when everyone lives and works in the community. We thus define the *Live-Work Index* as the ratio of commuting trips that *both* begin and end in the community and all commuting trips that *either* begin or end in the community.[9]

Before we can calculate the average Live-Work Index in our stratified sample of 40 U.S. metropolitan areas, we need to define what constitutes a community. At one extreme, an entire metropolitan area can be considered a community, where almost everyone both lives and works. A metropolitan area has a very high Live-Work Index value and is certainly a live-work community. At the other extreme, a residence of a single person who telecommutes from home has a maximum Live-Work Index value and is also a live-work community. For our analysis, however, we are interested in communities that are not too big and not too small and that are of similar land area. This would be in contrast to Cervero[10], for example, who calculated Thomas's *Index of Commuting*

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9 Using mathematical notation, the *Live-Work Index*, LWI_i, of community *i* is the number of commuting trips that both begin and end in the community, T_{ci}, divided by the sum of all commuting trips that either have their origin in the community, O_i, or their destination in the community, D_i, or both. When trips both originate and terminate in the community, we have $O_{ci} = D_{ci} = T_{ci}$. To eliminate double counting, we thus have $LWI_i = T_{ci}/(O_i + D_i - T_{ci})$. Clearly, when no trips both begin and end in the community, the Index attains the value of 0 and when all trips both begin and end in the community, the Index attains the value of 1.

10 Cervero, Robert, 1996. Jobs-housing balance revisited, *Journal of the American Planning Association* 62 (4), Autumn, 492-511.

Independence for 23 cities in the San Francisco Bay Area in 1990, cities that varied dramatically in land area—from San José (457 km^2) to Daly City (20 km^2). A comparison of the land areas of these cities with their Indices of Commuting Independence shows that the Index is significantly correlated with land area at the 2% confidence level: The larger the city area, the larger the Index. That suggests that we should only compare the Live-Work Index values of communities of similar, if not identical size.

This raises an important question: What would be the appropriate size of a live-work community? Ebenezer Howard suggested that an ideal garden city would be circular, with a radius of 1,240 yards (1.36 kilometers) and an area of 5.8 km^2. Earlier, in Section 4, we noted that the average area of Central Business Districts (CBDs) in the 50 largest U.S. metropolitan areas in 1970 was 8.4±1.5 km^2. In Section 5, we noted that the average size of employment sub-centers out side the CBD was 12.8± 2.6 km^2. Our interest in communities that allow for walking or bicycling to work suggests that, for purposes of analysis, an abstract live-work community in a contemporary American city would be a circle with a radius of 2 kilometers and a total area of 12.6 km^2, an area equal to the average area of an employment sub-center. The average beeline distance between two locations in such a circle is 0.9 kilometers, a distance that may lengthen to 1.1 kilometers along streets. Such a distance may be traversed in 22 minutes by walking leisurely at 3 kilometers per hour, a reasonable commuting distance by foot. The maximum beeline distance in such a community is 4 kilometers, a distance that may lengthen to 4.8 kilometers along streets, still a tolerable distance for commuting by bicycle. In other words, in a live-work community of this size we should expect the great majority of commuters to walk or bicycle to work.

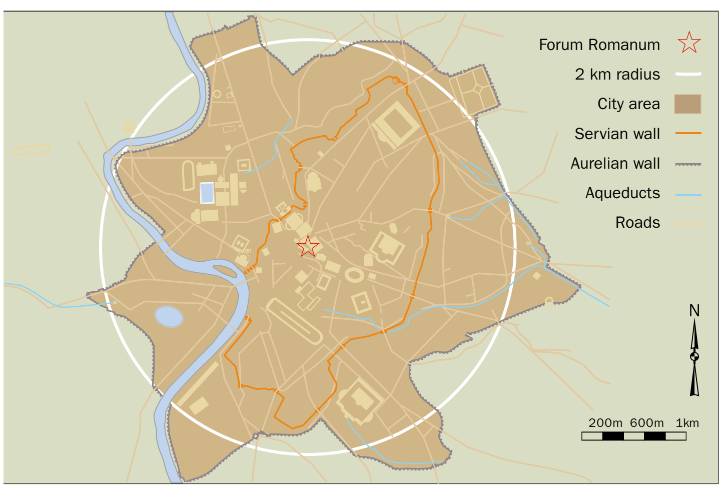

Figure 17: The walls surrounding Rome, built by the Emperor Aurelian in 271-275AD, encompassed a live-work community within a 2-kilometer radius of the *Forum Romanum*.

It is important to note here that all cities were walking cities until 1800, before the advent of mechanized transportation. One of the largest among them, Rome at the time of the Emperor Aurelian in the third century AD, was home to almost one million people and still a walking city. The emperor built a wall to encircle the city in 271-275AD, a roughly circular wall built at a distance of 2 kilometers from the *Forum Romanum* (see figure 17). This suggests to us that an area circumscribed by a circle with a 2-kilometer radius is a reasonable area for a contemporary live-work community where people are expected to walk or bicycle to work. It is certainly not too small, but it is also not too large. Surely, the question before us relates to cities that are far larger in area than Rome of Aurelian's day, whose walls encompassed an area of 13.7 square kilometers. The average urbanized area in the sample of 40 U.S. metropolitan areas in our stratified sample is 1,750±620 square kilometers, an area that could contain a mosaic of some 130 non overlapping live-work communities the size of ancient Rome. That said, the Live-Work Index we defined here is likely to attain a higher value in very small cities. At the extreme, a city the size of ancient Rome will attain a value of 1 on this index. The smallest city in our sample, Pueblo, Colorado, had an urbanized area of 140 km^2, only 10 times that of ancient Rome. And as we shall see below, the 8 cities in Group 5—the group with the smallest cities in our sample—had considerably higher Live-Work Index values than cities in the remaining four groups.

As we noted earlier, the *Live-Work Index* measures the degree to which the Mosaic of Live-Work Communities model correctly describes the spatial structure of contemporary American metropolitan areas. More specifically, we can calculate the average share of all commuter trips that shared common live-work communities—defined as circles with a 2-kilometer radius—in our stratified sample of 40 U.S. metropolitan areas. If we found that share to be substantial, namely if the large majority of commuters in these metropolitan areas—say more than half—resided and worked in live-work communities, then we could claim that this model is a viable one. If, however, only a small minority of commuters resided and worked in live-work communities we must reject this model as a viable description of the spatial structure of contemporary American metropolitan areas.

To find the average value of the Live-Work Index in a given city in our sample, we constructed a random set of possible communities in the city. We selected a set of random points within the urbanized area of the city and constructed a set of communities as circles with a 2-km. radius around each random point. In each city in the sample, depending on its urbanized area, the number of communities we selected was large enough to ensure that the total area of communities was equal to *twice* the urbanized area. By ensuring substantial overlap among the communities we selected, we sought to ensure both that the entire urbanized area was covered and that no community with an exceptionally high Live-Work Index was likely to be missed. In each community, we then identified all the census-tract centroids it contained and estimated the following metrics: (1) the set of all intra-tract commuter trips in the community; (2) the set of all inter-tract commuter trips in the community; (3) the set of all commuter trips originating in the community and ending outside it; and (4) the set of all commuter trips originating outside the community and ending inside it. This, in turn, allowed us to calculate (1) the Live-Work index for all communities in the city; (2) the average Live-Work Index for the city as a whole; and (3) A 95% confidence interval for this average. These average values with their confidence intervals, as a function of the area of the city, are shown in figure 18.

Figure 18 shows that the average value of the Live-Work Index for all cities in the sample was 7.7±0.8%, and that all cities in the sample had average LWI values that were below 15%. More specifically, it shows that in 35 out of 40 cities in our stratified sample—and in all cities with urbanized areas in excess of 550 km^2—the average value of the Live-Work Index was less than 10%. We can conclude, therefore, that on average, for American cities as a whole, less than 10% of commuters live and work in the same community; more than 90% live in one community and work in another. In fact, in only one city in the sample, Columbia SC, did we find a single community where more than half of commuters, 58% to be precise, both lived and worked there. Four cities in the sample—Boston and Nashua MA, Portland ME, and Ashville NC—had single communities where more than one-third but less than one- half of commuters both lives and worked there. And in all other 35 cities in the sample, there was not even a single community to be found where more than one-third of commuters both live and worked there. Given this evidence, we must reject the Mosaic of Live-Work Communities model as a viable model for describing the spatial structure of contemporary American cities.

But we can now asked a related question that does not mandate that people live and work in the same community but that they have short commutes: Given the contemporary spatial structure of American cities, how many workers could potentially walk or bicycle to work if walking and biking were facilitated by public policy, say by facilitating or mandating the creation of short city blocks as well as of sidewalks and bike paths, and by insisting on making walking and biking safer as well as more pleasant?

Figure 19 shows the average shares of commute trips in the 40 cities in our stratified sample that had a beeline distance of less than 4 kilometers (implying a street distance of the order of 4.8 kilometers), as well as the average share of trips that had a beeline

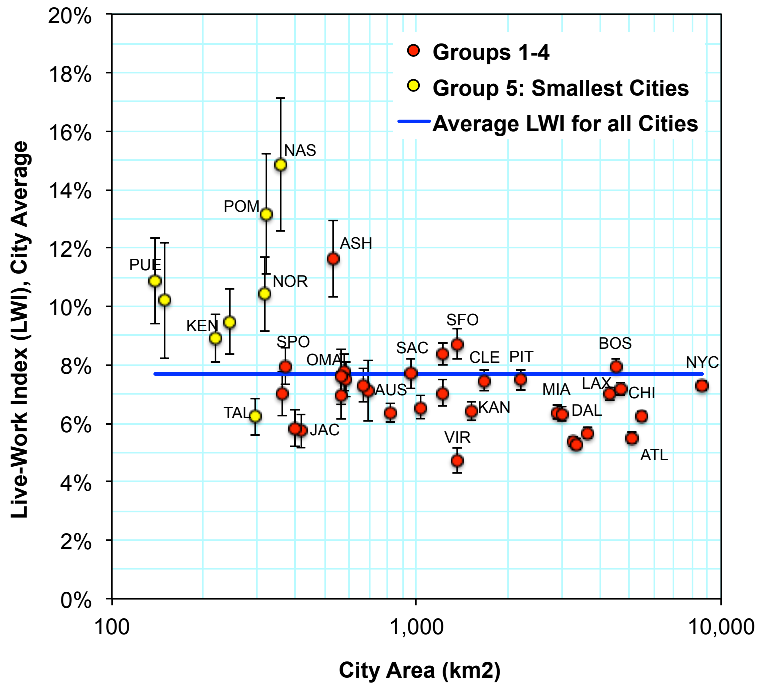

Figure 18: Average values of the Live-Work Index in a stratified sample of 40 American cities in 2000.
Note: Vertical bars represent 95% confidence intervals for the city averages.

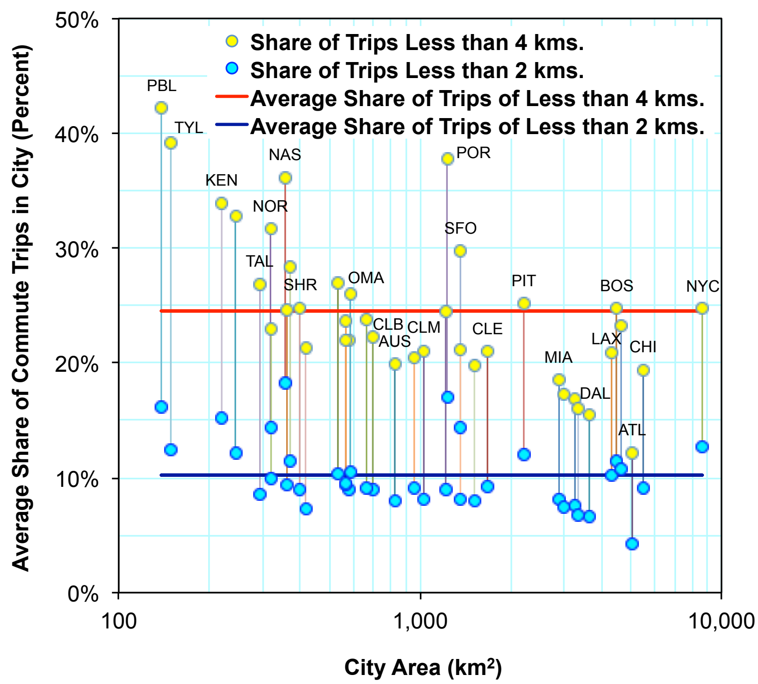

Figure 19: Average shares of commute trips that had a beeline distance of less than 4 and less than 2 kilometers in a stratified sample of 40 American cities in 2000.

distance of less than 2 kilometers (implying a street distance of the order of 2.4 kilometers). These are distances that could be comfortably covered by bicycle and by a brisk walk respectively in 30 minutes, distances and times that could be considered tolerable commuting ranges. These shares are found to be quite large: For the 40 cities as a whole, an average of 24.1±2.1% of trips could be within tolerable commuting range by bicycle and an average of 10.2±1.0% of trips could be within tolerable commuting range by foot. These numbers suggest that commuting by bicycle could potentially increase by as much as 40-fold and walking to work could increase more than 3-fold, both very substantial increases indeed. Yet even if such increases were to be realized—a very demanding scenario by any stretch of the imagination—still the great majority of commute trips, 3 out of 4 trips on average, will remain outside the range of bicycling or walking to work, requiring longer-range modes of transport, namely transit or some form of door-to-door conveyance with a range and efficiency similar or greater than that of the private automobile.

7. Summary and conclusion: The evidence supports the *Constrained Dispersal* model

The evidence presented in this second part of the article allows us to conclude that:

- The *Maximum Disorder* model is not a viable description of the spatial structure of contemporary American cities because
  - The average commute distance predicted by the model, assuming that commuting takes place between a random residence and a random job in a stratified sample of 40 American metropolitan areas, is 24.5±4.6 kilometers, a significantly longer distance than the observed average commute distance in these metropolitan areas, 10.3±0.9 kilometers; and
  - The model predicts that jobs will be dispersed throughout metropolitan areas and that there will be no concentrations of jobs, but there are significant concentrations of jobs, both in the Central Business Districts (CBDs) of cities (10.8±3.1% of all jobs, on average) and in employment sub-centers (13.8±2.0% of all jobs, on average).
- The *Mosaic of Live-Work Communities* model is also not a viable description of the spatial structure of contemporary American cities because
  - The average commute distance predicted by the model, assuming that all commuting takes place within live-work communities, is 1.8 kilometers, a significantly shorter distance than the observed average commute distance in these metropolitan areas, 10.3±0.9 kilometers; and
  - On average, in our stratified sample of 40 American cities in 2000, only 7.7±0.8% of commuters live and work in the same community. Namely, more than 90% live in one community and work in another.
  - The great majority of commuters live beyond the tolerable commute range by bicycle or by foot: In our stratified sample of 40 American cities in 2000, an average

of 24.1±2.1% of trips could be within tolerable commuting range by bicycle and an average of 10.2±1.0% of trips could be within tolerable commuting range by foot.

- The *Monocentric City* model is also not a viable description of the spatial structure of contemporary American cities because
    - The average commute distance predicted by the model, assuming that all commuting takes place between randomly-located residences and the city center in a stratified sample of 40 American metropolitan areas, is 20.1±3.8 kilometers, a significantly longer distance than the observed average commute distance in these metropolitan areas, 10.3±0.9 kilometers; and
    - The model assumes that the great majority of jobs are located in Central Business Districts (CBDs). On average, in the 50 largest American cities in 2000, only 10.8±3.1% of all jobs were found in CBDs. The great majority of jobs—8 out of 9 jobs, on average—were located outside CBDs.
- The *Polycentric City* model is not also a viable description of the spatial structure of contemporary American cities because
    - The model assumes that the great majority of jobs are located either in Central Business Districts (CBDs) or in dense employment sub-centers scattered throughout the metropolitan area. On average, in the 50 largest American cities in 2000, only 13.8±2.0% of jobs were located in employment sub-centers, and only 24.6±1.8% of all jobs were found either in CBDs or in employment sub-centers. The great majority of jobs—3 out of 4 jobs, on average—were located outside CBDs or employment sub-centers.
- Only the *Constrained Dispersal* model is a viable description of the spatial structure of contemporary American cities because
    - The model predicts that both commuters and workplaces will relocate so as to be within tolerable commuting range of each other. It thus predicts that average commute distance in cities, found to be 10.3±0.9 kilometers in a stratified sample of 40 American cities in 2000, will be significantly shorter than those predicted by the Maximum Disorder model or by the Monocentric City model, found to be 24.5±4.6 kilometers and 20.1±3.8 kilometers respectively. It also predicts that it will be significantly longer than the predicted average commute distance—1.8 kilometers, on average—if everyone lived and worked in live-work communities.
    - The model predicts that the dispersal of jobs throughout metropolitan areas will be substantial—involving the great majority of jobs— significantly more than that the dispersal predicted by the Monocentric City and the Polycentric City models (0%) yet significantly less than that predicted by the Maximum dispersal model (100%). In the 50 largest U.S. metropolitan areas in 2000 we found that 75.4±1.8% of jobs—namely 3 out of 4 of jobs, on average—were dispersed. The rest were located in

CBDs or employment sub-centers. The great majority of jobs were dispersed as predicted by the model, yet their dispersal was constrained by agglomeration economies of one kind or another keeping one-quarter of all jobs, on average, clustered together in employment centers.

- The Constrained Dispersal model is, in essence, a *hybrid* model that combines elements of all other models. It postulates that the Maximum Disorder model is largely correct, except that in applies only to 3 out of 4 jobs and not to all jobs, and except that commuters and workplaces move to be within a tolerable commute distance of each other. It postulates that the Mosaic of Live-Work Communities model is correct, except that it only applies to 1 out of 12 commute trips. It postulates that the Monocentric City model is correct, except that it applies only 1 out of 8 of jobs rather than to all jobs. And it postulates that the Polycentric City model is also correct, except that it only applies to 1 our of 4 jobs. In general, it postulates that the Maximum Disorder model is constrained by weak, yet effective, attractive forces that bring residences and workplaces closer to each other and by weak, yet effective, attractive forces that brings workplaces closer to other workplaces.

If the Constrained Dispersal model is indeed the model that correctly captures the spatial structure of present-day American cities, what are the implications for transport and land use policies? We begin to address this question in the concluding section of this paper.

III The Implications for Transport and Land Use Policy

The key finding in this study is that the large majority of jobs or commuter destinations in American metropolitan areas—3 out of 4 jobs, on average—are now dispersed throughout them, outside the Central Business District (CBD) and outside employment sub-centers. A related finding is that average commute distances are quite long—10.3±0.9 kilometers, on average—and that most commutes—3 out of 4, on average—are beyond biking distance.

While we do not have to accept this state of affairs as “the best of all possible worlds”, as Voltaire’s *Candide* would have it, we do have to acknowledge it and to understand that the future of our cities is path dependent: The cities of the future will be variations on the cities of today and, barring catastrophes and calamities of one kind or another, any changes in their spatial structure and their built form are likely to be gradual and marginal, building upon their existing spatial structure. The same observation also applies to commuting patterns: Most commuting patterns are quite likely to be between dispersed residences and dispersed workplaces for a long time to come.

The conclusion of our companion paper, “Commuting and the Productivity of American Cities”, was that American metropolitan areas now function as single, integrated labor markets where workers and workplaces are matched at a truly metropolitan scale. We concluded that the most important productivity advantage of larger cities is the larger size of their labor markets and the greater choice it offers both workers and workplaces. We found that larger cities with larger labor markets are more productive than smaller ones. And we also found that larger cities have more integrated labor markets in the sense that they facilitate access to jobs through three cumulative adjustments: densification, the relocation of jobs and residences to be within a tolerable range of each other, and the increased use of higher-speed transport modes. The policy implications of these findings are that the more integrated metropolitan labor markets are, the more productive they are. We should therefore support policies that increase overall regional connectivity; policies that allow for speedier rather than slower commuting, for more rather than less commuting, and for longer rather shorter commuting to take advantage of metropolitan-wide economic opportunities; and policies that remove impediments to the locational mobility of residences and workplaces for all income groups so that they can easily relocate to be within tolerable commute range of each other.

Given the results of this paper, we can now look more closely at the relationship between the productivity of American cities and their spatial structure. We can ask ourselves: Are cities that have a larger share of their jobs and residences clustered in CBDs, in employment sub-centers, or in live-work communities more productive or less productive than cities that conform to the Constrained Dispersal model?

Our provisional answer to this question, in the absence of rigorous evidence to the contrary, is that the advantages offered by clustering are now largely *metropolitan* in scale. Namely, the agglomeration economies associated with clustering—a large and diverse labor pool, knowledge exchange within industries and across different sectors, shared infrastructure, shared inputs, shared services and amenities, a diverse industry mix that reduces economic shocks, and the presence of large, internal markets are all metropolitan in scope rather than pertaining to concentrations of people and jobs *within* metropolitan areas. This conclusion is shared by a number of other authors (see, e.g., Burger et al, 2009; Gordon and McCann, 2000; Johansson and Quigley, 2004; Phelps and Ozawa, 2003). We concur, except for allowing for those rather weak effects that create and maintain CBDs and those rather weak effects that create and maintain employment sub-centers. We refer to them as 'weak' largely because they could not hold back the decentralization and dispersion of the great majority jobs into the suburbs and then away from employment centers altogether. They could only constrain them, preventing them from eventually creating an even more dispersed spatial structure that would have conformed to the Maximum Disorder model.

We could only find evidence, albeit rather sparse, that supports our contention and no evidence to counter it. Lee and Gordon (2007), for example, did not find that the share of jobs in the CBD or in employment sub-centers affected metropolitan population or employment growth, both of which can be considered indirect proxy variables for the productivity of cities. Meijers and Burger, in one of the only empirical studies that explored the effects of urban spatial structure on the labor productivity of U.S. cities, concluded that "[m]etropolitan areas with more dispersion do not perform worse in terms of labor productivity" (2010, 1398). We note that Meijers and Burger's study referred to the dispersion of population and not to the dispersion of jobs. Our own multiple regression test of the 50 largest U.S. metropolitan areas in 2000 in Lee's dataset, with labor productivity measured in metropolitan area GDP per worker as the dependent variable and the number of jobs in the city, the average density of jobs in the city, the share of jobs in the CBD, and the share of jobs in employment sub-centers as independent variables found that only the number of jobs in the city had a significant effect on labor productivity. The shares of jobs in the CBD or in employment sub-centers did not.

As for the productivity of live-work communities, we may recall the aforementioned insights of Alonso who noted that "seeking closure at a small scale may economise on certain inputs (such as those of commuting) but results in lower per capita production"(Alonso, 1970, 44). We may also recall the recent *Economist* article that concluded that "the lesson of the new towns is that being linked into a bigger city fosters growth…. The notion that they would be self-contained economies has largely failed" ("Paradise Lost", *The Economist*, 3 august 2013). In other words, the productivity of self-contained live-work communities should be lower than the productivity of communities that form parts of larger metropolitan areas.

In the absence of rigorous evidence to the contrary, we cannot conclude that the Constrained Dispersal model of urban spatial structure in inherently less efficient and less productive than the Monocentric City model, the Polycentric City model, or the Mosaic of Live-Work Communities model. This does not necessarily commend it as optimal in any way. In truth, the Constrained Dispersal structure of American cities has been enabled by—we might even say has come into existence by—the car (and the truck), abetted by tax and subsidy policies favoring highways and single-family homes and by regulatory regimes favoring low-density 'green field' development. And this has come at a price, the price exacted from cities conforming to this spatial structure becoming dependent on the car and the truck for their continued productivity and prosperity. This symbiosis between the highly dispersed spatial structure of American cities and the highly efficient door-to-door long-distance commute offered by the private automobile is reflected by the current statistics of the travel times and modal choices of commuters: According to the *2009 American Community Survey*, the national average travel time to work was 25.1 minutes and only 7.5% of all commuters required more than one hour to reach their workplace. Out of a total of some 138 million workers, 86.1% used a private automobile (of which 10.0% shared one), 5.0% used public transit (of which 2.2% used fixed-rail transit and 2.8% used buses), 0.6% bicycled to work, 2.9% walked to work, and 4.3% of worked at home (1.2% used other modes: taxi, ferry, motorcycle etc.). This symbiosis between Constrained Dispersal and the private automobile is also reflected in the statistics on household car ownership: In 2013, for example, only 4.5% of commuter households did not have a car available. In fact, only one-third of commuters who chose public transport to get to work did not have a car available.

It is not difficult to conclude that the continued reliance on the private automobile for travel to work and the increasing dispersal of workplaces away from the CBD and away from employment sub-centers represented by the Constrained Dispersal model are mutually reinforcing. The ready availability of cars makes it possible for workplaces to disperse throughout the urban area—occupying low-rise buildings on cheaper and lower-taxed land with ample parking in less congested neighborhoods—without sacrificing their productive edge. And the formation of large metropolitan labor markets, accompanied by the dispersal of jobs away from the CBD and away from employment sub-centers, both require and allow workers to travel to work by car—usually beyond walking and biking range but within a tolerable commute range of their chosen place of residence—to reach the better paying, more productive jobs available to them in the metropolitan area.

That said, acknowledging the symbiosis underlying the productivity of contemporary American metropolitan areas, is in no sense an endorsement of the continued use of the private automobile as we know it today, neither for urban travel in general nor for commuting and business travel in particular. Much can be done to improve its performance, to reduce its carbon emissions, to automate it, to price its use correctly, and even to make it driverless; and much can be done to improve the use of the road network through better use of road space, through better traffic management, through correct road pricing and through the completion of the road network with additional links. The key prerogative for us is to understand that the productivity of American cities as they have come to be relies on efficient long-distance door-to-door transport among dispersed locations, a function that at the present time can be fulfilled only by the private automobile and by no other mode. Transportation improvements and investments should therefore focus, as an important policy priority, on improving or replacing the private automobile with a better, more efficient and more environmentally friendly alternative; a more equitable one that is not careless about the carless. In American cities with a Constrained Dispersal spatial structure, neither fixed-rail rapid transit (with or without feeder busses), nor busses, nor bicycles offer attractive alternatives to meet the commuting needs of their integrated metropolitan labor markets, where three quarters of jobs are scattered in dispersed locations throughout the metropolitan area.

This acknowledgement, to emphasize yet again, is not an endorsement of the Constrained Dispersal model as an optimal model of urban spatial structure, one to be preferred over other models. There is much to be said in favor of more clustered cities or for cities where more people live and work in the same community, and much has been written in support of both of these models. Changes in tastes and cultural preferences and novel improvements in transportation technology, in building technology, or in the regulatory regime governing transportation and land use may indeed lead to gradual yet observable changes in urban spatial structure in the coming years. Whether they would lead to changes that are radical enough to transform the spatial structure of American cities in fundamental ways is altogether another matter. For now, we must continue to press for marginal improvements. Increasing the number of people who work at home, increasing the share of workers who live and work in the same community, increasing the share of people who walk to work or bicycle to work, increasing the share of people who use public transport will all act to increase the number of people who live and work in CBDs and employment sub-centers, as well as the number of people who live and work in the same community, and all will reduce our reliance on the private automobile, if only in marginal ways.

And reducing our reliance on the private automobile we must. We have arrived at a juncture in the lives of our cities and metropolitan areas where their continued productivity may hinge on reigning in greenhouse gas emissions in general—and those produced by cars in particular—so as to slow down global warming. In all probability, reigning in greenhouse gas emissions would entail reducing overall mobility. This will certainly have important implications for the productivity of American cities. Mobility has been broadly defined as "the ability to travel where you want when you want, to connect to places in the metro area you might want to go" (Staley and Moore 2009, 4). And although commuting requires mobility, it only accounts for approximately one quarter of all person miles traveled in the U.S. Commuting contributes uniquely to the productivity of urban regions, however, by linking workers and workplaces with one another. Thus while commuting accounts for a relatively small percentage of total travel and, of necessity, not the most pleasant share of travel, it constitutes a dimension of metropolitan mobility that warrants policy focus. And a focus on making commuting more efficient or more equitable is quite different from a focus on enhancing mobility at large. If, to take one example, travel on transportation networks was priced at higher rates during peak travel periods—while offering discounts for carpools, say—people with discretionary non-commute trips might choose to travel at non-peak times.

Mobility is typically measured in Vehicle Miles Travelled (VMT) and emerging concerns with limiting greenhouse gases will most probably require an overall reduction in VMT in the coming years to meet vehicle emission goals. Research on the relationship between economic activity and VMT (OTREC, 2011) suggests that although causality often runs both ways—increased economic activity generates increased travel and increased travel generates more economic activity—the relationship is complex and often runs in one direction: increased economic activity generates increased travel. However, the OTREC study does not differentiate commuting from mobility at large. Our contention is that a renewed emphasis on commuting as against mobility for mobility's sake will focus our attention and our policy interventions on the causal connection between VMT—specifically the VMT required to commute—and economic activity. This type of VMT—which we may call *productive* VMT—should be encouraged and allowed to increase, if necessary, because greater access to jobs means a better fit between workers and jobs and, in turn, an increase in overall productivity. If we do need to limit greenhouse gas emissions, we should focus on reductions in *non-productive* VMT—the VMT that we consume more of when our incomes increase—not in the productive VMT, the VMT we need to increase the productivity of our cities.

Transportation policies can facilitate commuting by promoting transport modes and routes that help the great majority of actual commuters get to work—from their actual homes to their actual workplaces—rather than by focusing on transport modes and routes that help relatively few, perhaps at the expense of many. We must weigh the benefits of favoring local travel, or linear travel to employment centers, against the cost of restricting metropolitan-wide travel, or more generally, the prospect of harming the majority of commuters by promoting plans that serve a minority. We must insist that any deliberate policy change in this structure must ensure, at the very minimum, that it does not improve a small part of the urban transportation and land use system while risking its overall productivity. In confronting the relentless challenges to the transport and land use systems that undergird our cities, we must ever remain vigilant—as Alonso warned us earlier—against being penny-wise and pound-foolish. Our small agendas must give way to the broader ones, those that aim to preserve and sustain the productivity and vitality of our great metropolitan areas.

At their best, land use and transport policies contribute to the productivity of metropolitan areas when regulations, taxes and subsidies, and public investments respond to two complementary forms of demand: First, they respond to the demand for unrestricted residential and workplace mobility, namely the demand of workers and workplaces to move freely from one location to another so they can be within tolerable commuting ranges of each other. Second, they respond to the demand for the best fit between workers and workplaces, namely the demand of workers to reach their most productive choice of workplace during the morning rush hour and to return to their homes during the evening rush hour quickly and economically. The dominance of the Constrained Dispersal model in contemporary American metropolitan areas informs us that, for the great majority of commuters today, responding to this second form of demand calls for regulations, taxes and subsidies, and public investments that support longer-range metropolitan travel between dispersed locations, namely travel beyond walking and biking distance between dispersed residential and job locations outside the Central Business district (CBD) and outside employment sub-centers.

For us, there is no escape from the conclusion that some form of long range door-to-door conveyance—an improved yet unrealized version of the private automobile of today—is the transportation mode best suited to the spatial structure of both present and future American cities, a spatial structure best characterized by the Constrained dispersal model and one that cannot be expected to change in radical ways any time soon. It is long-range door-to-door conveyance that both gives form to these cities and sustains and maintains their very large metropolitan labor markets, integrated labor markets that now form the very core of their unparalleled agglomeration economies, the economies are the very foundations of their economic productivity. We conjecture that the future prosperity of American cities in the coming decades may rest on an improved version of this long-range door-to-door conveyance, rather than on replacing it with other, less effective transport modes: increasing its energy efficiency, decreasing its reliability on non-renewable fossil fuels, making better use of road space and increasing traffic safety—possibly through the conversion of the car fleet to driverless vehicles, vehicles that can also serve those who cannot drive and do not require parking in congested areas.

Productive cities are rarely planned and built from scratch. They evolve from the myriads of actions of their inhabitants. They are works in progress and they remain works in progress, responding, as indeed they must, to new challenges and new opportunities. American cities have now evolved a highly dispersed spatial structure and a highly flexible door-to-door long-distance commute system that are in a symbiotic relationship with each other: the door-to-door long-distance commute system both serves and generates this spatial structure and that spatial structure, in its turn, requires the door-to-door commute system to support and enhance it. Interventions aimed at improving transportation and land use in American cities in the coming years must acknowledge this symbiotic relationship as well as its durability before acting to change it for the better in both marginal and radical ways.

* * *

Annex 1: A Stratified Sample of 40 U.S. Urbanized Areas

While there are hundreds of academic articles and books written about commuting in America, there is a dearth of scientific knowledge about the *geography* of commuting in the country, knowledge of a general nature about commuting patterns in geographic space that can be applicable to all cities and all metropolitan areas. In the year 2000, for example, there were 242 metropolitan areas in the country that had 100,000 people or more. Each of these metropolitan areas had a unique geography of commuting consisting of unique descriptions of where people lived, where they worked, and where and how they traveled to get to work. What was of interest to us was the degree to which these unique descriptions shared some common patterns that could be observed in all cities. If they did, and if we could discern these patterns, we could gain some scientific knowledge on the geography of commuting, knowledge that could help us understand it better and then act on it in a more informed and intelligent manner. "Science," wrote Aldous Huxley (1958, 19), "may be defined as the reduction of multiplicity to unity. It seeks to explain the endlessly diverse phenomena of nature by ignoring the uniqueness of particular events, concentrating on what they have in common and finally abstracting some kind of 'law' in terms of which they make sense and can be effectively dealt with." This article is a modest contribution towards a science of cities and more specifically, towards understanding the geography of commuting in cities and its impact on their productivity. It is our belief that understanding this geography has serious implications for transport and land use policies and for guiding future investments in cities, especially for future investments in urban transport technology and infrastructure.

To be of use, such a study must be rigorous and comprehensive, relying on the use of simple and well-defined metrics and employing reliable and well-understood statistical methods. In this Annex, we summarize the methodology we applied in our research. Briefly, it consists of using the 'urbanized areas' of U.S. cities as the geographic loci of our study; selecting a large enough random sample of U.S. metropolitan areas; utilizing reliable commuting data obtained from the U.S. census; and organizing these data into simple metrics that can be compared across cities to discern the commonalities and differences in their spatial patterns of commuting.

1. The 'Urbanized Areas' of Cities

Any comparative study of metropolitan areas must begin with a consistent and rigorous definition of what constitutes a metropolitan area or, in other words, where are its outer boundaries. Unlike municipal boundaries, which relate to distinct and fixed administrative and political areas, the criteria for selecting metropolitan boundaries are less clear, not least because they change over time as cities grow and expand. In determining a universe of cities for the purpose of studying metropolitan labor markets, we were therefore interested in metropolitan boundaries that approximate the functional city—boundaries that separate dense urban areas from sparsely populated rural ones, that account for the spatial contiguity of built-up areas, and that take account of the flows of commuters linking urban locations to one another. In conceptual terms, this description corresponds to what one might consider the metropolitan area or the metropolitan labor market. In statistical terms, this description corresponds most closely to the *Urbanized Area* within the *Metropolitan Statistical Area* (MSA), as defined by the U.S. Census Bureau.

Our selection of the Urbanized Area as the unit of analysis may appear confusing at first, since the MSA already exists as a familiar census definition that seeks to encompass the metropolitan labor market. In determining the composition of MSAs, the Census Bureau identifies a central county or counties and then adjoins outlying counties based on the percentage of commute trips that originate outside but terminate inside the central county(s). Currently, at least 25 percent of a county's commute trips must terminate in the central county (or counties) for it to be part of an MSA. But MSAs are comprised of whole counties—the first-level administrative subdivisions of states—as their smallest building blocks, and the inclusion of entire counties ignores population densities, built-up areas, and the spatial contiguity of urban activities. MSAs can therefore include large expanses of rural areas as well as uninhabited deserts, wetlands, and mountainous terrains.

The definition of an Urbanized Area within the MSA, in contrast to the coarser definition of an MSA, uses both density thresholds and spatial contiguity rules to determine whether a given census block—the smallest geographic unit delineated by the census—belongs or does not belong to an Urbanized Area. A census block may be as small as one city block bounded by streets. The U.S. Census defines an Urbanized Area as an inhabited place of at least 50,000 people where the population density of census blocks is at least 1,000 persons per square mile (386 persons per square kilometer). The blocks must generally be contiguous, but there are exceptions where gaps of up to 2.5 miles (4 kilometers) are allowed to connect qualifying non-contiguous land. Urbanized area boundaries thus disregard political or administrative boundaries, such as states or counties. Two MSAs may border one another, but two Urbanized Areas that are contiguous to each other merge into a single geographic unit. And since Urbanized Areas are wholly contained within MSAs, they meet their commuting threshold criteria as well and can thus be considered as integrated labor markets. Urbanized Area boundary files for the cities in this study were obtained from the U.S. Census website.

Information about the inhabitants of census blocks is not publicly available as their populations are small and the concern for privacy is high. Blocks are aggregated into block groups (intended to contain between 600 and 3,000 people) that are aggregated into census tracts (intended to contain between 1,500 and 8,000 people with an optimum size of 4,000). Since urbanized areas are collections of census blocks, urbanized area boundaries may split census tracts and block groups, and they sometimes do.

We observed that urbanized areas are also very good approximations of the built-up areas of cities (see figure 20).

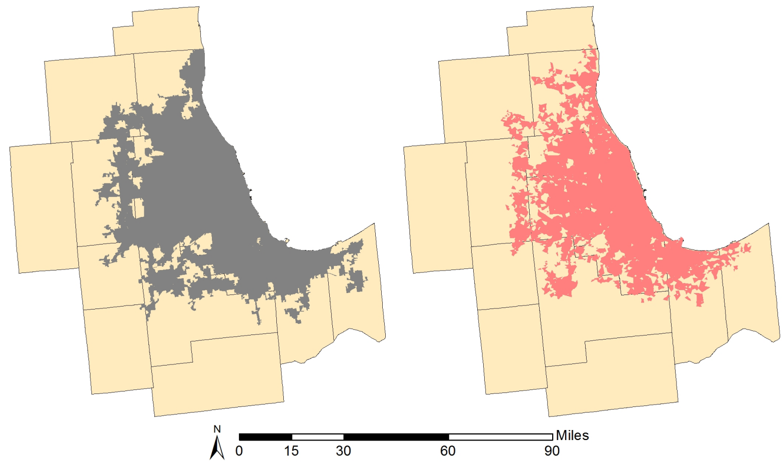

Figure 20. Thirteen counties comprising Chicago's MSA (yellow), Chicago's Urbanized Area in 2000 (grey) on left, and Chicago's built-up area in 2000 (red) identified by the *Modis 500 urban land cover map,* on right.

Figure 20 shows the difference in the spatial extent between the Chicago Metropolitan Statistical Area, its Urbanized Area, and its built-up area in the year 2000 as identified by *Modis500* satellite imagery with a 463-meter pixel resolution. The Chicago MSA (officially Chicago-Naperville-Joliet) is composed of 13 counties in three states (Illinois, Indiana and Wisconsin) with an area that is 3.3 times larger than the Chicago Urbanized Area, a ratio that is quite typical of MSA–Urbanized Area relationships throughout the United States. But, as the figure shows, the outer edges of the Urbanized Area of Chicago are not very different from those of its built-up area as identified by satellite imagery. The Urbanized Area thus corresponds, more generally, to our intuitive grasp of the limits of the city being the outer edges of its built up area, what the ancient Romans referred to as the *extrema tectorum*. The U.S. Census Bureau identified a total of 242 census-defined Urbanized Areas with 100,000 people or more in the year 2000. These Urbanized Areas were taken to comprise the sampling universe for our study. In our article, the terms urbanized area, metropolitan area, and city are used interchangeably to refer to the urbanized areas in this universe.

2. The Sample of 40 Cities

Our aim was to gain insight into broad-brush commuting patterns in the entire universe of U.S. cities. For that, it was necessary to select a large enough representative sample of cities and to compare them to each other. A random stratified sampling procedure was used to select 40 Urbanized Areas from the universe of all 242 U.S. cities that had populations of 100,000 or more in the year 2000. This universe of cities was ranked by population size in descending order and partitioned into five groups, so that each group contained roughly twice the number of cities in the previous group. Eight cities were then randomly selected from each group to obtain the final sample. Table 2 shows the characteristics of each of the five sampling subgroups, including the number of cities in each group, the total group population, and the characteristics of the selected sample cities. As expected, in the universe of U.S. cities as a whole there were a small number of very large cities, a larger number of intermediate size ones, and a much larger number of small ones. This conforms to the earlier findings of Zipf (1949) and Davis (1970). The number of cities in the sampling universe subgroups increased from 8 cities in Group 1, to 16 in Group 2, 32 in Group 3, 64 in Group 4, and 122 cities in Group 5. 100 percent of cities in the Group 1 were selected for the final sample while only seven percent of the cities in Group 5 (8 out of 122) were selected. A map displaying their locations of the 40 selected cities is shown in figure 21. Their names, three letter labels, populations and areas, and are given in table 3.

Group	Sampling Universe			Selected Sample Cities			
	Number of Cities	Total Population	Average City Population	Number of Cities	Total Population	Percent of Cities in Universe Group	Percent of Population in Universe Group
1	8	64,258,829	8,032,354	8	64,258,829	100.0%	100.0%
2	16	39,524,408	2,470,276	8	21,213,973	50.0%	53.7%
3	32	29,465,737	920,804	8	7,541,505	25.0%	25.6%
4	64	23,203,371	362,553	8	2,778,183	12.5%	12.0%
5	122	18,872,471	154,692	8	1,312,166	6.6%	7.0%
Total	242	175,324,816	724,483	40	97,104,656	16.5%	55.4%

Table 2. Characteristics of the Universe of U.S. cities in 2000 and of the Selected 40-City Sample

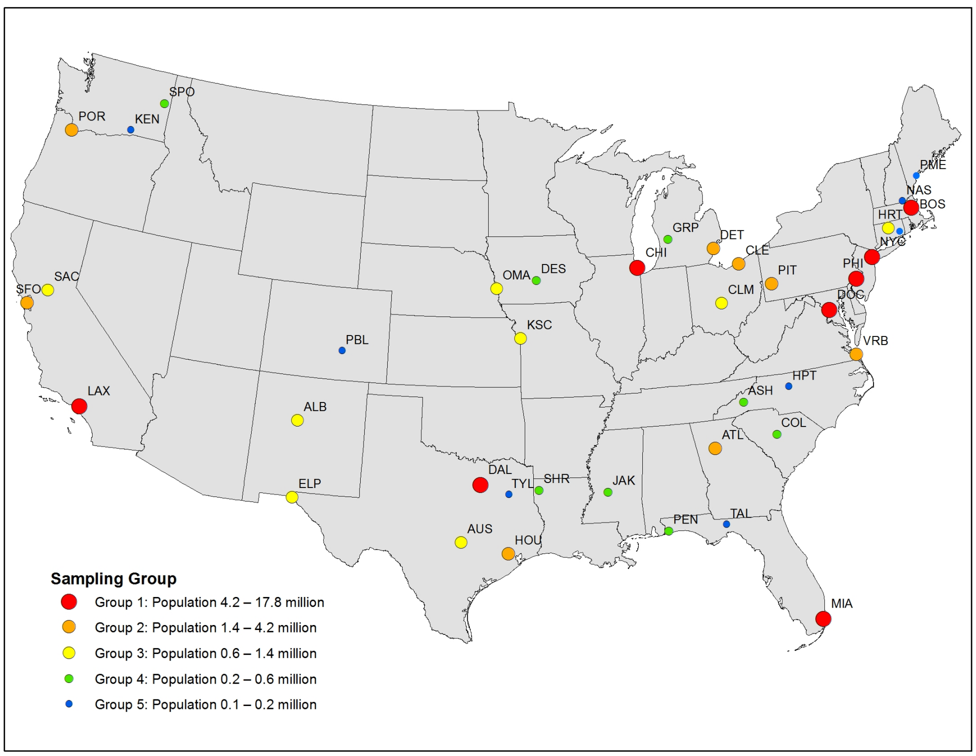

Figure 21: Locations of the 40 cities in the sample

Urbanized Area	Label	State(s)	Population, 2000	Area, 2000 (km²)	Population Group
New York - Newark	NYC	NY, NJ, CT	17,799,861	8,683	1
Los Angeles-Long Beach-Santa Ana	LAX	CA	11,789,487	4,320	1
Chicago	CHI	IL, IN	8,307,904	5,498	1
Philadelphia	PHI	PA, NJ, DE, MD	5,149,079	4,661	1
Miami	MIA	FL	4,919,036	2,891	1
Dallas - Fort Worth - Arlington	DAL	TX	4,145,659	3,644	1
Boston	BOS	MA, NH, RI	4,032,484	4,497	1
Washington DC	DOC	DC, VA, MD, DE	3,933,920	2,996	1
Detroit	DET	MI	3,903,377	3,267	2
Houston	HOU	TX	3,822,509	3,355	2
Atlanta	ATL	GA	3,499,840	5,083	2
San Francisco - Oakland	SFO	CA	3,228,605	1,364	2
Cleveland	CLE	OH	1,786,647	1,676	2
Pittsburgh	PIT	PA	1,753,136	2,208	2
Portland	POR	OR, WA	1,583,138	1,228	2
Virginia Beach	VRB	VA	1,394,439	1,364	2
Sacramento	SAC	CA	1,393,498	956	3
Kansas City	KSC	KS, MO	1,361,744	1,514	3
Columbus	CLM	OH	1,133,193	1,030	3
Austin	AUS	TX	901,920	824	3
Hartford	HRT	CT	851,535	1,216	3
El Paso	ELP	TX, NM	674,801	568	3
Omaha	OMA	NE	626,623	586	3
Albuquerque	ALB	NM	598,191	580	3
Grand Rapids	GRP	MI	539,080	667	4
Columbia	CLB	SC	420,537	697	4
Des Moines	DES	IA	370,505	363	4
Spokane	SPO	WA	334,858	371	4
Pensacola	PEN	FL	323,783	568	4
Jackson	JAK	MS	292,637	417	4
Shreveport	SHR	LA, AL	275,213	401	4
Ashville	ASH	NC	221,570	536	4
Tallahassee	TAL	FL	204,260	295	5
Nashua	NAS	NH, MA	197,155	357	5
Portland	PME	ME	180,080	321	5
Norwich - New London	NOR	CT	173,160	319	5
Kennewick - Richland	KEN	WA	153,851	220	5
High Point	HPT	NC	132,844	244	5
Pueblo	PBL	PA	123,351	139	5
Tyler	TYL	TX	101,494	149	5

Table 3. Characteristics of the 40 U.S. cities in the sample

3. Commute flow and distance data

The commute flow data used to derive distance calculations was extracted from the 2000 Census Transportation Planning Package (CTPP) *Part III Journey-to-Work* dataset, which contains commute flows between home and work census tracts for the entire country. The data set is based on full and part time workers 16 years or older of all classes (wage and salary, self-employed, private and public) who were at work during the reference week. Flow values between one and seven are rounded to four (presumably for privacy reasons), while flows over seven are often rounded to the nearest multiple of five as flows are often estimates based on statistical analyses performed by the Census Bureau. Only flows with both trip ends within the urbanized area were retained for our analysis. In Atlanta, for example, we observe 1,820,175 commute destinations within its urbanized area boundary, but only 1,795,651 of these destinations (98.7%) have origins within the boundary. The 24,524 destinations with origins outside Atlanta's urbanized area were excluded from our analysis.

Distances between tract pairs were calculated as beeline distances between their centroids. Since urbanized area boundaries may transect census tracts, particularly at the periphery, tract centroids were computed as the centroids of the urbanized area within a tract. Moreover, since a tract may contain urban area both within an urbanized area boundary as well as outside of it (if the contiguity rules for urbanized areas are not met at a peripheral tract, for example), only tracts with 100 percent of their urbanized land within the urban area boundary were retained for analysis. Ideally, average tract-to-tract distances would reflect average actual distances along the road network, but data on actual trip distances is not yet available. Distances between tract centroids and the Central Business District (CBD) were also calculated as beeline distances, where city hall coordinates were used as the centroid of the CBD. Actual average commute trip distances at the city level were calculated as the average of trip distances weighted by flows.

Annex 2: Sub-Centers in the 50 Largest Urbanized Areas

The identification of sub-centers in the 50 largest Urbanized Areas in the year 2000 was based on a dataset created by Dr. Bumsoo Lee. This information allowed us to calculate the number and share of jobs in the CBD, in sub-centers outside of the CBD, and outside sub-centers.

1. Defining Employment Sub-Centers

The ability to describe patterns of employment concentration across metropolitan areas has been of interest of urban economists, geographers, and theorists for over half a century. This knowledge has helped shape and reshape the development of urban economic models of spatial structure, and more generally, an understanding of spatial processes in cities over time. Crucially, however, the ability to describe patterns of employment concentration depends on the spatial scale of the measurement (county vs. zipcode vs. census tract level, for example), and whether the measure accurately accounts for the phenomenon of interest, be it total jobs, square footage of retail space, or sales volume.

The precision of measurements for employment activity has generally been of poorer quality than that of residential activity. This is no doubt related to the fact that the U.S. Census has historically focused on the enumeration of the residential population and not of businesses and the locations of their employees. In the past, scholars have benefited from urban travel demand forecasts that contained information for employment totals within small spatial units called *transportation analysis zones*. Such analyses were too infrequent to be of use for comparative studies and could typically be applied to only one city at a time. The Census Bureau's *Census Transportation Planning Package* data product, while containing somewhat coarser information than that provided by a city specific travel demand forecasting process, provides cross-sectional coverage for the entire United States. More recently, the development of the Census Bureau's *Longitudinal Employer Household Dynamics* program holds promise for even better information about employment and commuting flows. For our analysis, we were interested in a consistent and rigorous measure of employment concentration that could be applied to a large number of cities at a snapshot in time that was also consistent with our overall study.

Our literature review identified two primary empirical methods for identifying employment sub-centers. The first, introduced by Giuliano and Small (1991), combines employment density, *D*, and employment size, *E*, thresholds to spatial analysis zones. Contiguous zones that meet the density threshold become sub-centers if they meet the *E* target as well. In their study, for example, Giuliano and Small use *D=10* jobs per acre (approximately 25 jobs per hectare) and an *E=10,000* for total employment, which they lowered to *E=7,000* in outlying areas. They claimed this combination of *D* and *E* aligned with a theoretical understanding of sub-centers and that it generated results that were amenable to statistical and commuting analyses. Several researchers have adopted their approach with slight modifications. Cervero and Wu (1997) used *D=7* workers per acre and *E=9,500* total jobs in the San Francisco Bay Area; Bogart and Ferry (1999) used *D=8* jobs per acre and *E=10,000* total jobs in Cleveland, and Anderson and Bogart (2011) also used *D=8* jobs per acre and *E=10,000* total jobs in Cleveland, Indianapolis, Portland, OR and St. Louis. McMillen and McDonald (1998) raised *D* to 20 jobs per acre believing anything less would be too low for certain areas of Chicago. Matsuo (2011) experimented with a variety of *D* and *E* combinations in Atlanta, Boston, Phoenix, and Washington D.C. (*D=5, 10, 20,* and *30;* and *E=10,000; 20,000;* and *30,000*).

Determining appropriate *D* and *E* for identifying sub-centers is a rather subjective exercise that is ultimately the analyst's decision. There has been relatively little discussion of what appropriate values should be, whether uniform thresholds should be applied across different cities, or whether and by how much thresholds should vary. Clearly, raising density and employment thresholds will reduce the number of sub-centers while lowering thresholds will have the opposite effect. The size of the spatial unit of analysis can also affect sub-center calculations; the smaller the analysis zones, for instance, the finer the density calculation and delineation of sub-center boundaries.

The second method for identifying sub-centers, based on McMillen (2001), examines relative differences in employment density between a given zone and its surrounding areas. In other words, it seeks to identify the peaks and valleys of employment density and categorize those peaks or plateaus as sub-centers that have significantly higher densities than their surrounding areas. This is achieved using the technique of geographically weighted regression (GWR) that examines employment density differences between small and large area windows around the spatial analysis zone. Contiguous tracts with significant small-large window differences that meet a minimum density threshold are then identified as sub-centers.

2. The New Sample of 50 cities

Dr. Bumsoo Lee graciously shared with us his sub-center dataset for the largest 125 Urbanized Areas in the year 2000, used in Lee and Lee (2014). The dataset is remarkable for at least two reasons. First, it identifies sub-centers using the two classification methods described above (with slight modifications allowing for variation in the threshold values across cities; see Lee, 2007 and Lee and Gordon, 2011 for a more detailed description of the methodology). Second, it is applied to all 125 Urbanized Areas, far surpassing any previous comparative assessment of employment sub-centers in U.S. cities. The analysis is based on year 2000 *Census Transportation Planning Package* data that uses census tracts as the spatial unit of analysis.

In the interest of time and effort, we limited our sub-center analysis to the 50 largest urbanized areas by population. Twenty-one of the 50 largest cities are included in the stratified sample of 40 cities. Table 4 lists the 50 cities we used for our sub-center analysis, the three-letter label used on graphs, their associated states and populations, and whether they belong to the 40 city stratified sample. The number of sub-centers in each city varies depending on the classification method (Indexing vs. GWR), the unique pattern of peaks and valleys of employment concentration in each city, and the resolution of the zonal system used for density and size calculations. There is no *a priori* expectation for the difference in the number of sub-centers generated by indexing or GWR. We compared the number of sub-centers in all 125 cities using indexing and GWR. The latter resulted in a greater number of sub-centers in 60% of cities and fewer sub-centers in 18% of cities. Both methods yielded the same number of sub-centers in 22% of cities. A select list of cities in each category includes:

- *More sub-centers using relative method*: Chicago, Dallas, Houston, Los Angeles, New York
- *Same number of sub-centers, both methods*: Boston, Detroit, Louisville, Milwaukee, Tucson
- *More sub-centers using indexing*: Atlanta, Cleveland, Miami, Minneapolis, Seattle

It is unavoidable that different sub-center methodologies, threshold levels, and analysis zone sizes will yield different numbers of sub-centers. We were interested in establishing a more generous definition of sub-centers rather than a more restrictive one. Since GWR resulted in either the same amount of sub-centers or more than indexing in 88 percent of cases, and in the interest of adopting a consistent definition for all cities, we use the GWR results of Lee and Lee (2014) throughout our study.

Urbanized Area	Label	State(s)	Population, 2000	40-city sample?
Atlanta	ATL	GA	3,499,840	x
Austin	AUS	TX	901,920	x
Baltimore	BAL	MD	2,076,354	
Boston	BOS	MA, NH, RI	4,032,484	x
Bridgeport--Stamford	BRG	CT, NY	888,890	
Buffalo	BUF	NY	976,703	
Charlotte	CHR	NC, SC	758,927	
Chicago	CHI	IL, IN	8,307,904	x
Cincinnati	CIN	OH, KY, IN	1,503,262	
Cleveland	CLE	OH	1,786,647	x
Columbus	CLM	OH	1,133,193	x
Dallas--Fort Worth--Arlington	DAL	TX	4,145,659	x
Denver--Aurora	DEN	CO	1,984,889	
Detroit	DET	MI	3,903,377	x
Hartford	HRT	CT	851,535	x
Houston	HOU	TX	3,822,509	x
Indianapolis	IND	IN	1,218,919	
Jacksonville	JVL	FL	882,295	
Kansas City	KSC	MO ,KS	1,361,744	x
Las Vegas	LVG	NV	1,314,357	
Los Angeles--Long Beach--Santa Ana	LAX	CA	11,789,487	x
Louisville	LOU	KY, IN	863,582	
Memphis	MEM	TN, MS, AR	972,091	
Miami	MIA	FL	4,919,036	x
Milwaukee	MIL	WI	1,308,913	
Minneapolis--St. Paul	MIN	MN	2,388,593	
Nashville-Davidson	NSV	TN	749,935	
New Orleans	NOL	LA	1,009,283	
New York--Newark	NYC	NY, NJ, CT	17,799,861	x
Oklahoma City	OKL	OK	747,003	
Orlando	ORL	FL	1,157,431	
Philadelphia	PHI	PA, NJ, DE, MD	5,149,079	x
Phoenix--Mesa	PHX	AZ	2,907,049	
Pittsburgh	PIT	PA, NJ, DE, MD	1,753,136	x
Portland	POR	WA	1,583,138	x
Providence	PRO	RI, MA	1,174,548	
Richmond	RIC	VA	818,836	
Riverside--San Bernardino	RIV	CA	1,506,816	
Sacramento	SAC	CA	1,393,498	x
Salt Lake City	SLC	UT	887,650	
San Antonio	SAN	TX	1,327,554	
San Diego	SDG	CA	2,674,436	
San Francisco--Oakland	SFO	CA	3,228,605	x
San Jose	SJO	CA	1,538,312	
Seattle	SEA	WA	2,712,205	
St. Louis	STL	MO, IL	2,077,662	
Tampa--St. Petersburg	TMP	FL	2,062,339	
Tucson	TUC	AZ	720,425	
Virginia Beach	VRB	VA	1,394,439	x
Washington	DOC	DC, VA, MD	3,933,920	x

Table 4. 50 Largest Urbanized Areas (2000) used for Sub-center analysis

3. The Number and Share of Jobs in Sub-Centers

Lee's sub-center data contains a list of census tract identification codes for each city and columns describing which sub-center the tract belongs to under the different classification methods. We proceeded to create origin-destination matrices for each of the 50 cities. In the case of the 21 cities that belong to the 40-city stratified sample, the metropolitan level origin-destination matrix was already created for the analysis in our companion paper, "Commuting and the Productivity of American Cities". Like the companion paper analysis, origin-destination matrices were limited to trips with both trip ends inside the Urbanized Area.

Determining the total number and share of jobs in different sub-centers required aggregating tract employment totals into their corresponding sub-center and comparing this against the citywide total. Lee's dataset also indicates which sub-center is the CBD. Our inspection of sub-center maps confirms that the CBD is the always the 'historic' CBD, or the sub-center that contains the downtown area of the principal city in the metropolitan area.

* * *

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