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COMMUTING AND THE PRODUCTIVITY OF AMERICAN CITIES:

How self-adjusting commuting patterns sustain the productive advantage of larger metropolitan labor markets[1]

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ABSTRACT

The greatest productive advantage of modern-day American cities is that they form large and integrated metropolitan labor markets. We present new evidence on the importance of self-adjusting commuting and location patterns in sustaining the productive advantages of larger metropolitan labor markets, mitigating the difficulties in coping with their sheer size, and reducing the added burdens on their transportation infrastructure. As a result of these adjustments, the metropolitan labor market—defined as the actual number of jobs in the metropolitan area reached in less than a 1-hour commute—almost doubles in size when the workforce in a U.S. city doubles. More particularly, when U.S. metropolitan areas double in population, commute time should be expected to increase by a factor equal to the square root of 2. Instead, it only increases by one-sixth of that factor because of three types of adjustments that take place as cities grow in population: increases in residential density, locational adjustments of residences and workplaces to be within a tolerable commute range of each other, and increases in commuting speeds brought about by shifts to faster roads and transit systems. 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.

1 We are indebted to Alain Bertaud for insisting that urban transport policy and land use planning focus on metropolitan labor markets, and to Geoffrey West, Luis Bettencourt, and José Lobo for introducing us to scaling phenomena in cities—the regular variation of key urban phenomena with city population size. These two critical insights form the intellectual foundation of this work. Special thanks are due to Gregory Ingram for his detailed constructive comments on the manuscript.

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Introduction

It is generally understood that the main force propelling cities into being and then fueling their growth is their productivity. But in the heated debates on the future of our cities in general—and of our transport systems and land use patterns in particular—the specific and indeed essential role of our urban transport networks and our urban spatial structure in maintaining and enhancing the productivity of our cities is often misunderstood or rendered ambiguous (see, e.g. Litman, 2014). That said, there appears to be growing interest in integrating economic development goals in transportation and land use planning in American metropolitan areas. A recent white paper issued by the U.S. Department of Transportation, for example, acknowledges that economic development—"a fundamental societal goal of promoting growth in prosperity, economic opportunity, and the population's standard of living"—is "emerging as a priority topic in metropolitan area planning" (U.S. DOT 2014, 1). It is our firm belief that a renewed focus on the productivity of cities as a key objective in transportation and land use planning is indeed welcome. That said, the relationship between productivity on the one hand and transport and land use systems on the other is often misunderstood. The aim of this article is to bring a new understanding of this critical nexus to the fore.

How productive are American cities? The total amount of goods and services produced in the two largest metropolitan areas in America, New York and Los Angeles, in 2012—their combined Gross Domestic Product (GDP)—was 2.9 percent of that of the world at large. In comparative terms—to get a sense of the importance of the productive dimension of these cities—their combined GDP was also larger than that of India in that year, $2.1 versus $1.9 trillion (in current US$, World Bank, 2014; and BEA, 2013, table 1). Surely, these two metropolitan giants had many productive advantages over other places.

One of their most important advantages was that they functioned as integrated economies, and they were more productive as integrated economies *because* they were large. Why? In large part because larger metropolitan areas have larger metropolitan labor markets: workers have access to a larger, more diversified and more specialized pool of jobs, and firms have access to a larger, more diversified and more specialized pool of workers. These advantages—coupled with other metropolitan economies of agglomeration, such as shared knowledge, shared services and suppliers, shared risk of rapid changes in firm size, or increased competition—give larger cities their productive edge. As our study will demonstrate, metropolitan labor markets in the United States are held together by nimble and self-adjusting commuting patterns between self-adjusting residence and workplace locations that ensure that larger cities do not lose their productive advantage because of the added costs of long commuting trips along congested transport networks. And while commuting constituted only 28 percent of person vehicle miles travelled (VMT) by all modes (data for 2009, AASHTO 2013, table 2.1, 9), highly efficient commuting and location patterns that keep workers and workplaces within an acceptable commute range lie at the heart of the high productivity of American cities in general, and its larger metropolitan agglomerations in particular.

It stands to reason, therefore, that concerns for the effective contribution of commuting and location patterns to sustaining the continued productivity of American cities must guide future urban transport and land use policy, informing decisions regarding government spending, regulation, taxation, investment, and research. Unfortunately, such concerns have now been relegated to a minor, not to say insignificant, role in the public conversation on the future of urban transport and land use. This conversation—among academics, practicing transport engineers and city planners, the media, and the blogosphere—now focuses largely on environmentally sustainable transport and city building in the face of climate change and energy depletion. It typically celebrates local initiatives—such as biking, walking, mixed land use, and mixed income housing—while metropolitan-wide initiatives that are needed to facilitate the more familiar longer commutes are no longer seriously explored. It also centers on promoting traditional public transport connecting transit-oriented nodes of high employment and high residential density while, on average, three-quarters of workplaces are already located at low densities outside Central Business Districts and outside other high density metropolitan sub-centers. And it seeks to banish or, at the very least, rein in the private automobile, perceiving it to be environmentally unsustainable, depleting our energy supplies and polluting our atmosphere, while it continues to be essential for the great majority of our commuters to crisscross large, highly decentralized, low-density metropolitan areas on their way to and from their chosen jobs.

The central aim of this article is to present evidence that will shed new light on the key role that self-adjusting commuting and location patterns play in supporting metropolitan labor markets and hence in sustaining the productivity of cities. Additional evidence is presented in a companion paper following this one, titled "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". This evidence will hopefully inform a more pragmatic and more realistic conversation on the possible futures of urban transport and land use, a conversation that may determine whether our cities will become environmentally sustainable by harming their productivity or whether we can make the commuting and location patterns of the future—so critical to maintaining and enhancing the productivity of our cities—more efficient *and* more sustainable at the same time. At the end of the day, the productivity of our cities must be harnessed to secure their environmental sustainability, and our cities must become more sustainable so as to maintain their productivity.

The paper is divided into three sections and an annex. The first section of the paper focuses on the relationship between metropolitan labor markets and city size. We introduce data from the U.S. Bureau of Economic Analysis for 347 U.S. metropolitan areas to show that the larger the city, the more productive its workforce. We argue that *actual* versus potential access to jobs is the key to understanding the size of metropolitan labor markets. We find that the metropolitan labor market—defined as the actual *number* of jobs in the metropolitan area reached in less than a 1-hour commute—increased by 97 percent, i.e. almost doubled, when the workforce in a U.S. city doubles while the *share* of jobs that were reached within that time declined by a meager 1 percent.

The second section of the paper introduces and discusses the relationship between commuting time and city population size. The key finding in this section is that when U.S. metropolitan areas double in population, the increase in actual commute time is about one-sixth of the expected increase of 41 percent. In theory, other things being equal, average commute time should increase by the square root of 2 when city populations double, as we shall explain below. Observed actual increases are much lower because of three types of adjustments that take place as cities grow in population: increases in average residential density, the locational adjustments of residences and workplaces to be within a tolerable commute range of each other, and increases in commuting speeds brought about by shifts to faster roads or modes. Larger U.S. cities are denser than smaller ones, bringing workers closer to their jobs than they would be if densities were the same. Workers and their workplaces in larger U.S. cities move closer to each other to mitigate the increased average distance between any two locations in their larger areas, so that the time and distance of commutes remain within workers' *tolerable commute range*, their preference to remain within a limited time and distance from their workplaces when they select a residence or a workplace. And commuters in larger cities travel at higher average speeds on faster roads—freeways, for example, as against arterial roads—so that average commuting time increases at a slower rate than average commuting distance when city populations increase. The compound result of these three mutually reinforcing adjustments is that when city populations double, commuting time does not increase by 41 percent, as expected, but only by 7 percent.

The third section of the paper presents our conclusions and their implications for future urban transport and land use policy in American cities.

In the annex, we introduce the new database for our study: Journey-to-work data for a stratified sample of 40 U.S. urbanized areas in the year 2000. The urbanized area of cities—a U.S. Census category used to identify contiguous census blocks with a population density above a threshold considered to be urban—is found to be the appropriate way to define U.S. metropolitan areas for the purpose of studying commuting patterns. The study of these patterns in the entire universe of U.S. cities is simplified by focusing on a stratified sample of 40 cities, comprising one-sixth of all 242 urbanized areas in the country that were home to 100,000 people or more in 2000 yet containing 55.4 percent of their total population. Travel time data and travel flow data between census tracts were obtained from the U.S. census, while travel distances between tracts were calculated as beeline distances between their centroids because of lack of data on actual travel distances along roads.

I Metropolitan Labor Markets and City Size

The metropolitan labor market—defined as the actual number of jobs in the metropolitan area reached in less than a 1-hour commute—almost doubles in size when the workforce in a U.S. city doubles.

1. The larger the city, the more productive its workforce.

Urban theorists in general, and the economists among them in particular, have long sought to explain the emergence and growth of cities. Economists, as early as Adam Smith (1776) and Alfred Marshall (1890), recognized that cities bestow productivity advantages on both firms and workers. The productivity advantages of a large city then attract more firms and workers, increasing its population and its wealth, and these, in turn, make the city even more productive, creating, so to speak, a positive feedback loop. Several explanations have been put forth to explain why larger cities are more productive than smaller ones (for a review, see Duranton and Puga, 2004). One of the more important explanations for the higher productivity of large metropolitan areas—and one not sufficiently appreciated by transport and land use planners and by other urban policy makers—is that larger metropolitan areas have larger labor markets and this bestows upon them a great economic advantage, and possibly the most important one, over smaller ones.

Urban economic theory predicts that the larger the labor market, the greater the productivity of both firms and workers. Firms in larger cities have a larger—and, in addition, a more diverse—pool of workers to choose from and can therefore employ workers that are better fitted to the firm's specific requirements. The more fit workers are for their prospective jobs, the less on-the-job training they require, and the more valuable they are to the firm. Taken together, the firm's employees can then be more specialized, allowing the firm to reap the benefits of the division of labor and to become more productive. The firm thus becomes more profitable and can pay its workers better wages and salaries.

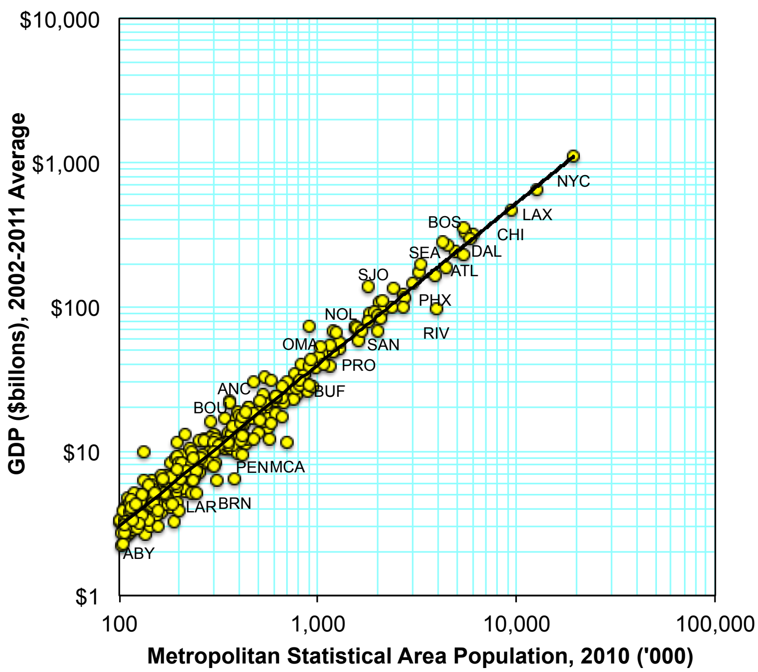

Figure 1: Average GDP, 2002-2011, as a function of the population of Metropolitan Statistical Areas (MSAs) in 347 U.S. MSAs with 100,000 people or more in 2010

In addition, large and diversified labor markets also allow firms to withstand both positive and negative shocks by quickly changing their labor profiles through hiring and firing workers. They allow firms to quickly fill vacancies. They also allow younger firms to experiment with different labor profiles before settling on the most productive ones. Workers, on their part, can choose from a greater pool of jobs, allowing them to find the jobs most suitable for their skills, aptitudes and temperaments, and income expectations. They also allow workers to find jobs that allow them to interact with knowledgeable workers, speeding up their learning, expanding their contact networks, and therefore their job prospects and their future earnings. The higher productivity of firms and the higher wages of workers attract more firms and more workers, thus enabling larger cities to continue to grow their economies and their populations.

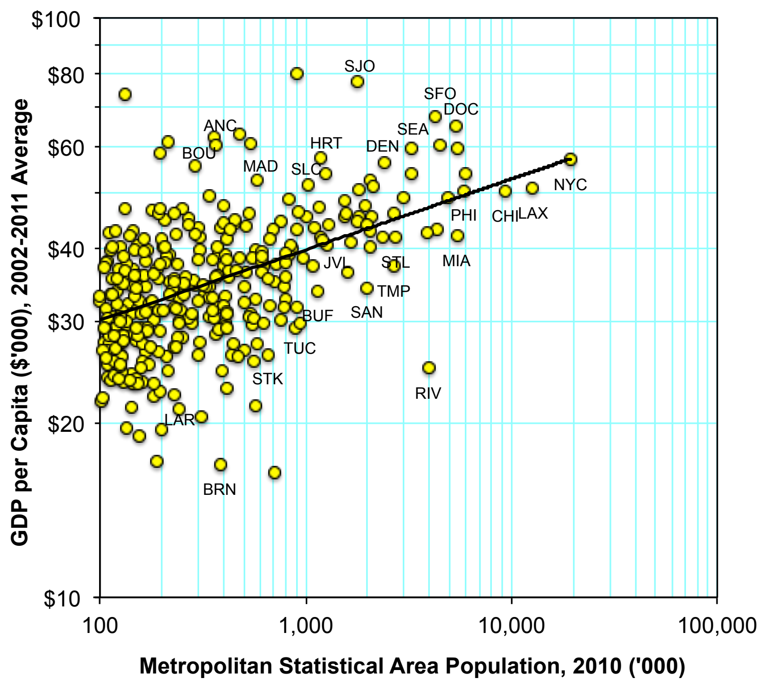

Figure 2: Average GDP per capita, 2002-2011, as a function of the population of Metropolitan Statistical Areas (MSAs) in 347 U.S. MSAs with 100,000 people or more in 2010

A simple method to measure the productivity of U.S. cities is by the Gross Domestic Product (GDP) of their Metropolitan Statistical Areas (MSAs), published annually by the U.S. Bureau of Economic Analysis (See, e.g. BEA, 2013). The average GDP for the years 2002-2011 for each MSA as a function of its 2010 population in plotted in figure 1 for all 347 MSAs with populations of 50,000 or more in 2010. The average GDP per capita for the years 2002-2011 for each MSA as a function of its 2010 population is plotted in figure 2.[1] Figure 1 shows that when cities doubled in population their Gross Domestic Product more than doubled: it increased by 120%. The relationship between the total economic output in a metropolitan area and its population is exceedingly strong, with

[1] These two graphs, like all graphs that appear in subsequent pages, are drawn with logarithmic scales on both the x-axis and the y-axis. The data is fitted with a power function of the general form $y = ax^b$, where a and b are constants. The linear regression equation that best fits the data is obtained by taking the logarithms of both sides of this equation, $Ln(y) = bLn(x) + Ln(a)$, or $Ln(y) = bLn(x) + c$ which is a linear equation, and that is why the regression line in the log-log graph is a straight line. The power function shown in figure 1 for the Gross Domestic Product, G, as a function of the population of the the metropolitan area, P, is $G = 0.0062P^{1.14}$ $(R = 0.96)$, so that $G(2P) = 0.0062(2P)^{1.14} = 2^{1.14}G(P) = 2.2G(P)$, namely the gross domestic product of a city with double the population P is 2.2 times the gross domestic product of the city with population P. The corresponding function for Gross Domestic Product Per Capita, G_c, shown in figure 2, is $G_c = 6145.9P^{0.14}$ $(R = 0.28)$, so that $G_c(2P) = 1.1G_c(P)$.

nearly 96 percent of the variation in GDP explained by population alone ($R^2 = 0.96$). Figure 2 shows that when metropolitan area populations doubled, their GDP per Capita increased by 10%. That relationship is weaker, but still statistically significant ($R^2 = 0.28$). Given these robust results, we must conclude that the larger the city, the more productive its workforce.

2. Actual versus potential access to jobs: A clarification

Although metropolitan areas become more and more productive the larger they become, they cannot and do not grow without limit. Larger cities occupy larger areas. Workers in larger cities may therefore face longer commuting distances to their workplaces and—if travel speeds do not increase sufficiently to compensate for these longer distances—longer commuting times as well. The added distance—and hence the added time and cost—of commuting in larger metropolitan areas are not insignificant and may compromise the economic advantage larger cities enjoy over smaller ones because of their larger workforce and the larger number of jobs they offer. Prud'homme and Lee (1999,1853), for example, suggest that

> [I]n large cities, the effective size of the labor market is very different from the total number of jobs in the city. In Seoul, the average worker has in 60 minutes access to only 51 percent of the jobs offered by the city; and the average enterprise has only 56 percent of the workers in less than 60 minutes.

If that were indeed true, it would mean that the actual size of Seoul's metropolitan labor market is only half the size of its workforce, thus compromising the great productive advantage that its large workforce could provide. Our study of a stratified sample of 40 U.S. metropolitan areas in 2000 suggests that, at least in the case of the U.S, this may not be the case. We find that the size of metropolitan labor markets in U.S. cities—defined as the *actual* number of jobs in a metropolitan area reached in less than a 1-hour commute—almost doubles in a city with double the number of workers. In other words, in a U.S. city with a workforce of some 2.5 million, e.g. Philadelphia, 91% of workers reached their jobs in less than 60 minutes. In a U.S. city with twice that workforce, e.g. Los Angeles—a city that had a similar size workforce to that of Seoul studied by Prud'homme and Lee—90% of workers reached their job in less than 60 minutes, 60 minutes being an arbitrary tolerance range for a commute. These percentages are considerably higher than those observed by Prud'homme and Lee in both Korean and French cities. Why?

One possible reason could be that U.S. cities in general, and Los Angeles in particular, have better and faster transportation systems than that of Seoul, as well as higher residential and workplace mobility. That may well be the case, but it would only explain a part of the difference in the data. The key difference in the data is in how one measures the size of a metropolitan labor market. Prud'homme and Lee, as well as other urban economists studying metropolitan labor markets (e.g. Melo *et al*, 2012) use a different metric for measuring the overall size of these markets than the one we use: the average number of *potential* jobs available *from a given residence* within a given time limit, say a one-hour commute. And to calculate the average accessibility in a city with this metric, they effectively assume that particular workers cannot move to a different residence to get closer to their particular jobs. In their perception of metropolitan labor markets, the location of a given residence must be fixed, and access to jobs is then calculated as the average access to job locations from all the fixed locations of residences in the city.

But any *potential* measure of the size of metropolitan labor markets ignores two important facts. First, most potential jobs—even within one's own industry, so to speak—are not of interest to particular workers who commute to their particular jobs. Second, as we shall see in Section II below, particular workers can and do adjust the location of their residences to get within a tolerable commute range of the jobs of their choice. In other words, the location of their residence is not fixed. Indeed, metropolitan labor markets are shaped and reshaped by the locational choices of firms *and* residences *and* by the travel choices that commuting among them requires. These choices create a dynamic equilibrium that can and typically does keep jobs within reach of workers and workers within reach of jobs, regardless of the size of metropolitan areas. Hence, while the number of potential jobs within, say, a one-hour commute of all fixed locations cannot and does not increase indefinitely with the size of city's workforce, the number of actual jobs reached within that time limit does indeed. We thus define the size of metropolitan labor markets not by the *potential* access to jobs they may offer but by the *actual* number of workers in the metropolitan area that reach their jobs within a given time constraint, say one hour. Thus, the reason that we estimate U.S. metropolitan labor markets to be much larger than those measured by others is that our definition measures actual access to jobs of real-world commuters rather than access to potential jobs by would-be commuters from fixed residential locations. It may indeed be true that in Seoul, a worker may only have half the jobs in the city at a tolerable commute range from her fixed location, but with one residential move she may have access to most of the other half.

We should keep in mind that if workers can relocate then the whole country, and possibly the whole world, can be taken to be a single labor market. This is true, and in certain industries, say genetic engineering or professional soccer, this is already the case. For most jobs, however, this is not the case. Long-distance relocation is typically costly and not without risk, especially when the new job is insecure. It may require a change of climate and language, separation from family members and friends, a new job for one's spouse and a new school for ones' children, as well as high search costs in strange faraway places and a long period of adjustment to an unfamiliar environment. Such costs and risks are greatly reduced when one moves within a metropolitan area that is already familiar, where information on jobs, houses, and schools is easier to come by. *Craigslist*, to take one example, organizes its want ads and job offers in lists that closely approximate a metropolitan labor market.

The question remains whether metropolitan labor markets are singular—namely consisting of a single labor market for the entire metropolitan area—or segmented in space into several relatively independent sub-markets. Commuting data on origins and destinations in our sample of 40 U.S. cities can shed some light on this question. At the very least, they provide visual evidence that strongly suggests that each metropolitan area consists of a single labor market. In figure 3, 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.

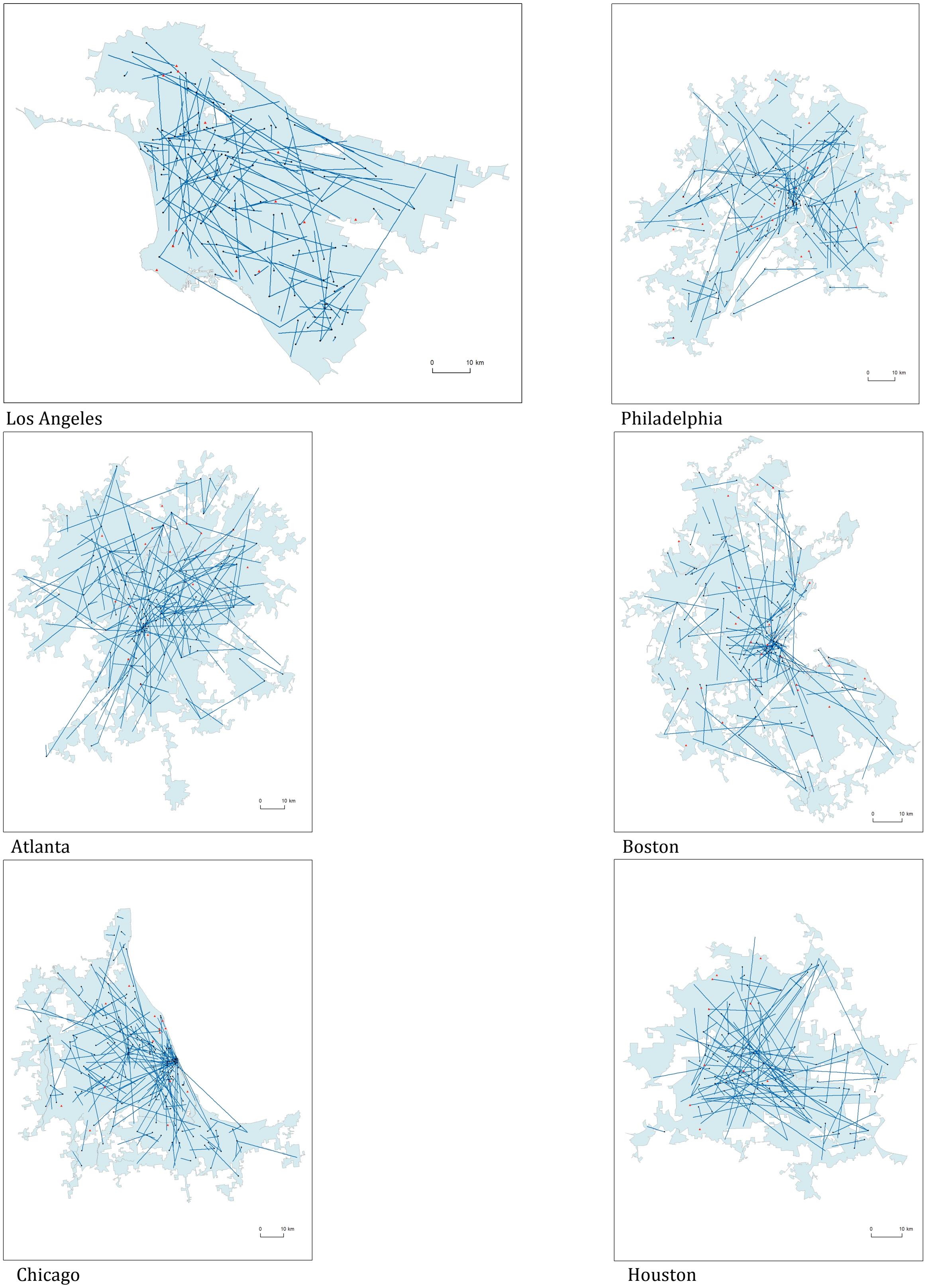

Figure 3: 200 randomly selected Origin-Destination commute pairs in six American cities, 2000

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 of origin-destination pairs in each city 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 because we found by repeated experimentation that larger numbers of lines simply fill the urbanized areas 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 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 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 these six representative cities begin to suggest that, in each and every city, the residences and workplaces of commuters do not congregate to form spatially distinct labor sub-markets. Commuters travel from residences throughout the metropolitan area to workplaces throughout the metropolitan area, implying that the metropolitan area is a single labor market. That said, more advanced spatial statistics are needed to confirm these results and to identify outliers that do not conform to the overall pattern. The Philadelphia metropolitan area may be one of them: The Delaware River—dividing it in two from the southwest to the northeast—appears to break the metropolitan labor market into two distinct sub-markets. That said, our preliminary investigations confirm that this example may be the exception rather than the rule. In general, American metropolitan areas, large and small, are single, integrated labor markets. And it is this unity that gives them their productive advantage.

3. Metropolitan labor markets and city population size

Given our definition of metropolitan labor markets, we found a very strong relationship between the number of jobs that are actually reached within a given time and the total number of jobs in a U.S. city (see figure 4). Figure 4 shows that the number of jobs within a 60-minute commute range increased systematically—by 97%, 3% short of 100%, to be exact—in a city with double the number of jobs; that the number of jobs within a 45-minute commute range increased by 94%, 6% short of 100%, in a city with double the number of jobs; and that the number of jobs within a 30-minute commute range increased by 87%, 13% short of 100%, in a city with double the number of jobs. In the 40 U.S. cities studied, the power functions representing these relationships all fit the observed data with an R^2 of 0.99.[2] This must be interpreted to mean that in cities with double the

[2] The power function shown in figure 4 for the number of jobs with a less than 60-minute commute, N_{60}, as a function of the number of jobs in the metropolitan area, J, is $N_{60} = 1.23J^{0.98}$ (R =0.99), so that $N_{60}(2J)$ =

numbers of jobs, the number of jobs accessed within a tolerable commute range increased by a fixed multiple, almost doubling the number of jobs accessed within that range.

To take a specific example: In 2000, the New York metropolitan area had 7.6 million jobs and the Chicago metropolitan area had 3.8 million. In other words, New York had twice the number of jobs that Chicago had. New York provided 85% more jobs that were reached in less than 60 minutes than Chicago did (6.2 vs. 3.6 million); 83% more jobs that were reached in less than 45 minutes than Chicago did (5.3 vs. 2.9 million); and 82% more jobs that were reached in less than 30 minutes than Chicago did (3.7 vs. 2.0 million). We must conclude, therefore, that the added friction created by the need to commute further and for a longer time in larger cities did compromise the size of their metropolitan labor markets, but only to a very minimal extent. The size of the metropolitan labor market—defined as the *number* of jobs that could be reached within a given time—almost doubled in cities with double the number of jobs or, more generally, with double the population.

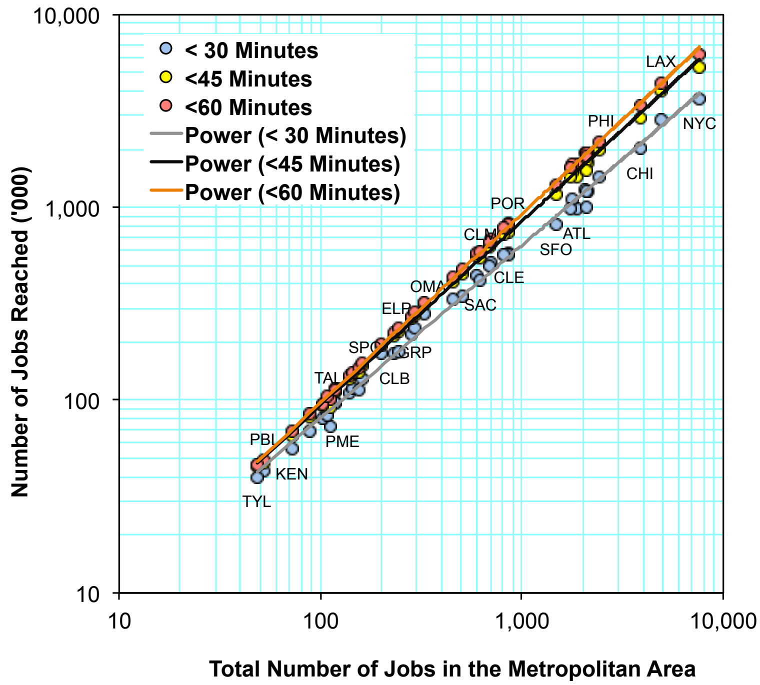

Figure 4: The actual numbers of jobs reached in less than 30, 45 and 60 minutes as functions of the total number of jobs in 40 U.S. cities in 2000

The fact that the size of the metropolitan labor market *almost* doubled, but did not exactly double, must be examined in more detail by looking at the *share* of jobs in a metropolitan area that was reached within a given tolerable commute range. If that share were to stay fixed regardless of city size, then the size of metropolitan labor markets would exactly double when the city population or its workforce doubled. Examining the commuting data for the 40 U.S. cities in our sample in 2000, we found that this share declined slowly but steadily when city populations or, more specifically their workforces, increased in size. The relationship between the share of jobs that could be reached within a given tolerable commute time and the total number of jobs in the city is shown in figure 5. Figure 5 shows that the share of jobs within a 60-minute commute range declined systematically—by 1%, to be exact—in cities with double the number of jobs; that the share of jobs within a 45-minute commute range declined by 3% in cities with double the number of jobs; and that the share of jobs within a 30-minute commute range declined by 7% in cities with

$1.97N_{60}(J)$; for less than a 45-minute commute it is $N_{45} = 1.61J^{0.95}$ (R =0.99), so that $N_{45}(2J) = 1.94N_{45}(J)$; and for less than a 30-minute commute it is $N_{30} = 2.75J^{0.89}$ (R =0.99), so that $N_{30}(2J) = 1.86N_{30}(J)$.

double the number of jobs. The power functions fitted to the data still had excellent statistical fit—their R^2 values in the range of 0.50-0.75—suggesting that the share of jobs reached within a given tolerable commute range declined slowly yet systematically with the total number of jobs in the city.[3]

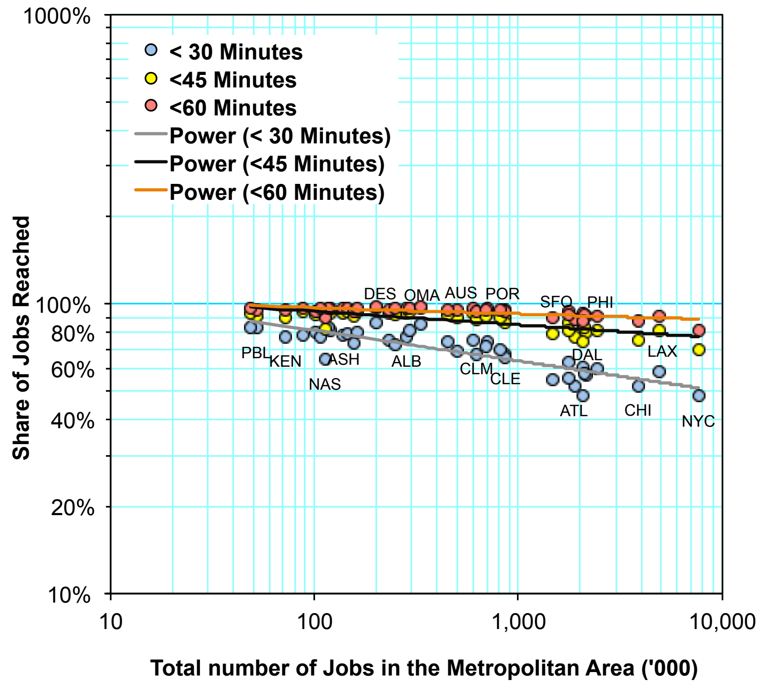

Figure 5: The actual shares of jobs reached in less than 30, 45 and 60 minutes as functions of the total number of jobs in 40 U.S. cities in 2000

Again, to take a specific example: In 2000, the Los Angeles area had 4.9 million jobs and the Sacramento metropolitan area had 0.62 million. In other words, Los Angeles had 8 times the number of jobs that Sacramento had. In Sacramento, 94% of all jobs were reached in less than 60 minutes, compared to 90% in Los Angeles. 88% of all jobs in Sacramento were reached in less than 45 minutes, compared to 81% Los Angeles. And 67% of all jobs in Sacramento were reached in less than 30 minutes, compared to 58% in Los Angeles. In a large metropolitan area like Los Angeles, therefore, nine-tenths of the total jobs were reached in less than 60 minutes, and three-fifths were reached in less than 30 minutes. We must conclude, therefore, that the added friction created by the need to commute further and longer in larger cities did compromise, to some extent, the potential size of their metropolitan labor markets. Indeed, the *relative* size of the metropolitan labor market—defined as the *share* of jobs that could be reached within a given time—declined systematically but the *number* of jobs in its labor market practically doubled when the size of a city population doubled.

These robust findings should dispel the concerns often voiced by urban economists that larger cities lose their productive advantage because of the added costs of long commuting trips along congested street networks. They demonstrate that even in the largest U.S. cities, the great majority of the workforce commuted for less than 60 minutes in 2000, and that when a city's workforce doubled in size, its metropolitan labor market—measured by the number of workers that actually reached their workplaces in less than 60 minutes, 45 minutes or 30 minutes—almost doubled in size as well.

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[3] The power function shown in figure 5 for the share of jobs with a less than 60-minute commute, S_{60}, as a function of the number of jobs in the metropolitan area, J, is $S_{60} = 1.23J^{-0.021}$ (R =0.50), so that $S_{60}(2J) = 0.99S_{60}(J)$; for less than a 45-minute commute it is $S_{45} = 1.61J^{-0.046}$ (R =0.60), so that $S_{45}(2J) = 0.97S_{45}(J)$; and for less than a 30-minute commute it is $S_{30} = 2.75J^{-0.106}$ (R =0.75), so that $S_{30}(2J) = 0.93S_{30}(J)$.

II Commuting Time and City Size

When U.S. metropolitan areas double in population, commute time should be expected to increase by a factor equal to the square root of 2. Instead, it only increases by one-sixth of that factor because of three types of adjustments that take place as cities grow in population: increases in residential density, locational adjustments of residences and workplaces to be within a tolerable commute range of each other, and increases in commuting speeds brought about by shifts to faster roads and transit systems.

The aim of this section is to introduce evidence from our stratified sample of 40 U.S. metropolitan areas in the year 2000 that shows that as city populations double, the actual increase in average commuting time is only one-sixth the expected increase. As city populations double, other things being equal, commuting time should be *expected* to increase by a factor of $\sqrt{2}$ as we shall explain below, in other words, by 41%. The *observed* increase, as we shall see, is only 7%. This is due to the three compounded adjustments or changes that take place when cities grow in population: densification, residential and workplace relocation that keep commuting times within tolerable commute ranges, and greater traffic mobility.

1. The square root of 2: The expected increase in average commuting time when city populations double

When comparing two cities with the same average population densities, the same average commuting speeds, and one with double the population of the other, what would be the expected increase in the average commuting time in the larger city?

Case 1: We begin by examining the expected increase in the special case of a *monocentric city* where residential densities do not vary with distance from the city center. We assume that the two cities, one with double the population of the other, are both circular in shape; workers' residences are uniformly distributed throughout their urban areas; the average residential density is the same in both cities; workers commute in straight lines and at equal speeds; and all jobs are concentrated at their city centers or Central Business districts (CBDs). If densities in the two cities are the same, then the area of the larger city will be exactly twice as large as the area of the smaller one, namely $A_2 = 2A_1$, or $2\pi(R_2)^2 = \pi(R_1)^2$. Hence $R_2 = R_1\sqrt{2}$. It can be ascertained[4] that the average distance D_i from any point in a circle to its center is $2R_i/3$. Therefore, $D_1 = 2R_1/3$, $D_2 = R_2/3$ and $D_2 = D_1\sqrt{2}$. If average speeds were the same everywhere, average travel time to the CBD would also increase by a factor of $\sqrt{2}$ in a city with double the area and, if average densities are the same everywhere, in a city with double the population as well, namely $T_2 = T_1\sqrt{2}$.

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[4] See Math Forum @ Drexel online at http://mathforum.org/library/drmath/view/62529.html.

Case 2: Let us now look at the special case of the *perfectly decentralized circular city*. We assume that the two cities are the same in all aspects as those described in Case 1, except that in this case we assume that instead of all jobs being concentrated at the CBD we have (5) jobs are evenly distributed throughout the urban area. It can also be ascertained[5] that the average distance *D* between any two points in a circle is $128R/45\pi = 0.9054R$. In other words, *D* is proportional to *R* and again we have $D_2 = D_1\sqrt{2}$.

In both cases, we see that the average commuting distance *D* is proportional to the square root of the area of the city. When the area of the city doubles, the average commuting distance *D* increases by a factor of $\sqrt{2}$. Needless to say, if commuters travel at equal speeds, average commuting time will also increase by a factor of $\sqrt{2}$.

Case 3: Let us now look at the average distance between any two points in a *perfectly decentralized city of any shape*. This city is the same as the one described in Case 2, except that it is no longer circular in shape. In two cities with the same non-circular shape where one is double the area of the other, there is a one-to-one correspondence between any point in the smaller one and a corresponding point in the larger one. This is illustrated in figure 6. The reader can ascertain by examining this figure that distances between any pair of corresponding points increase by the same factor, $\sqrt{2}$, when the area of that shape doubles. The average *D* of all those distances will, therefore, also increase by the same factor, $\sqrt{2}$, as well, and again we have $D_2 = D_1\sqrt{2}$. More generally, if commuters travel at equal speeds and job and residential densities are the same everywhere, average commuting time increases by a factor of $\sqrt{2}$ when the population of a perfectly decentralized city of any given shape doubles while its shape remains the same.

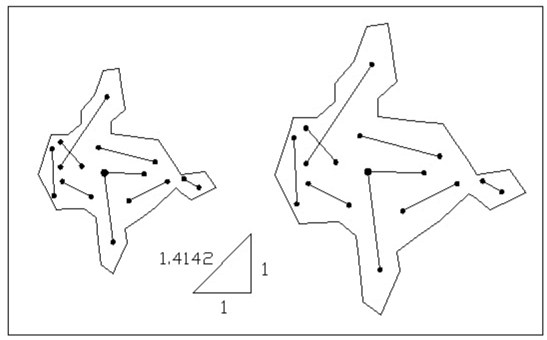

Figure 6: Distances between corresponding pairs of points increase in length by $\sqrt{2}$, or by 1.4142, in two cities with the same shape with the right one double in area

Case 4: Let us now look at the average distance between any two points in two *perfectly decentralized cities of different shapes*, where the area of one is double the area of another. In these cities both residences and jobs are distributed evenly throughout the urban area. We graphed the average beeline distance from a random sample of point locations to all other points in the sample in every city against the area of that city in our stratified sample of 40 U.S. cities in 2000 (see figure 7). We found that when city area doubled, that average distance between random locations

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

increased by 1.38 i.e. within 3% of $\sqrt{2}$. The relationship between the average distance between random points and the area of cities in the sample was systematic and robust (R^2 = 0.91).[6] Again, we can conclude that if commuters travelled at equal speeds and both residential and job densities were uniform everywhere, average commuting time between all locations in the city would be expected to increase by a factor of $\sqrt{2}$ when the population of a city doubled even if its shape did not remain the same.

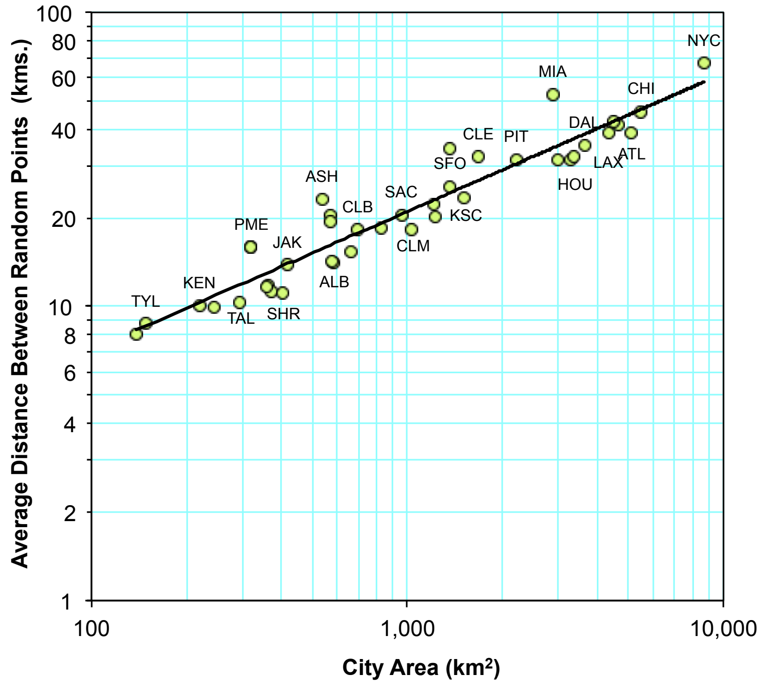

Figure 7: Average distance between two random locations in the city as a function of city area in a sample of 40 U.S. metropolitan areas in 2000

The common result of these four cases is that when city populations double, while their densities and travel speeds remain uniform and identical, average commuting times can be expected to increase by a factor of $\sqrt{2}$ or by 41%. Job and residential locations in real cities are not perfectly centralized nor perfectly decentralized but fall somewhere in between. And since at both extreme centralization and extreme decentralization we observe that when city areas double, average commuting distance increases by a factor of $\sqrt{2}$, we should expect it to increase by the same factor of $\sqrt{2}$ in real cities with non-uniform distributions of jobs and residences. We can thus answer the question posed at the beginning of this section as follows: When comparing two cities with the same average population densities and the same average commuting speeds, one with double the population and area of the other, the expected average commuting time in the larger city should increase by a factor of $\sqrt{2}$, or by 41%.

In reality, we found that in our stratified sample of 40 U.S. cities in 2000, when city populations doubled, the actual average commuting time increased, as expected, but it increased by a much smaller factor than $\sqrt{2}$. It is our contention, as we stated earlier, that it did so because of three compounded adjustments that took place in larger cities, adjustments that were necessary for maintaining the economic advantage of their larger labor markets. First, average densities in larger cities increased, so that when city populations doubled, their areas less than doubled and average

6 The power function shown in figure 7 for the average distance between two random points D_R, as a function of the city area, A, is $D_R = 0.82A^{0.47}$ *(R =0.91)*, so that $D_R(2A) = 1.38D_R(A)$.

commuting distance therefore increased less than expected. Second, workers and workplaces in larger cities adjusted their locations to be within tolerable commuting range so that the average distance to work became smaller relative to the average distance among all locations in the city. And third, mobility in larger cities improved, resulting in faster average travel speeds and further reducing the expected increase in average commuting time. We examine and explain the evidence regarding these three adaptations and their cumulative effects on average commuting time in American cities in the remainder of this section.

2. Larger U.S. cities are denser than smaller ones

Examining a stratified sample of 40 U.S. cities and metropolitan areas in 2000, we found that when the population of a city was double that of a smaller one, its area was only 70% larger than that of the smaller one. Its area did not double in size because larger U.S. cities have higher population densities than smaller ones: population density increased, on average, by 18% when city populations doubled. This is illustrated in figure 8. The graph shows the relationship between the total area of a city and its total population in 40 U.S. cities in 2000. The data is fitted with the power function, as before. According to this power function, when the city populations doubled, their areas did not double, but only increased only by 70%. As the graph shows, the relationship between the area of a city and its population is very robust ($R^2 = 0.94$).

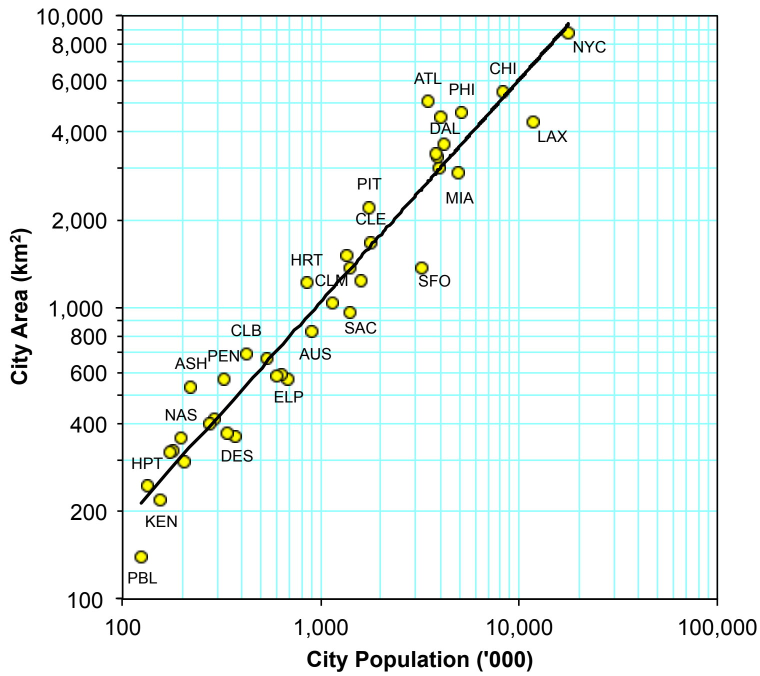

Figure 8: City area as a function of city population size in 40 U.S. metropolitan areas in 2000

Figure 9 explains why the area of a city with double the population did not double. It shows the relationship between the average population density in the city and its total population in our sample of 40 U.S. cities in 2000. Again, the data is fitted with a power function. According to this function, when city populations doubled, their average population densities increased by 18% ($R^2 = 0.60$). And when population density increased by a factor of 1.18, its reciprocal—city area per person—decreased by that factor. So, when the population of a city doubled, its area did not increase by a factor of 2 but only by a factor of 1.7 (2/1.18 = 1.7), namely by 70%. Other things being equal, if the area of a city increases only by a factor of 1.7 when its population increases by a factor of 2, then the average commuting distance in the city should increase by a factor of $\sqrt{1.7}$ =

1.3, namely only by 30% rather than by 41%.[7] In other words, the higher density of larger cities in the U.S. brings their residences and workplaces into closer proximity and thus significantly reduces the average commuting distances among them.

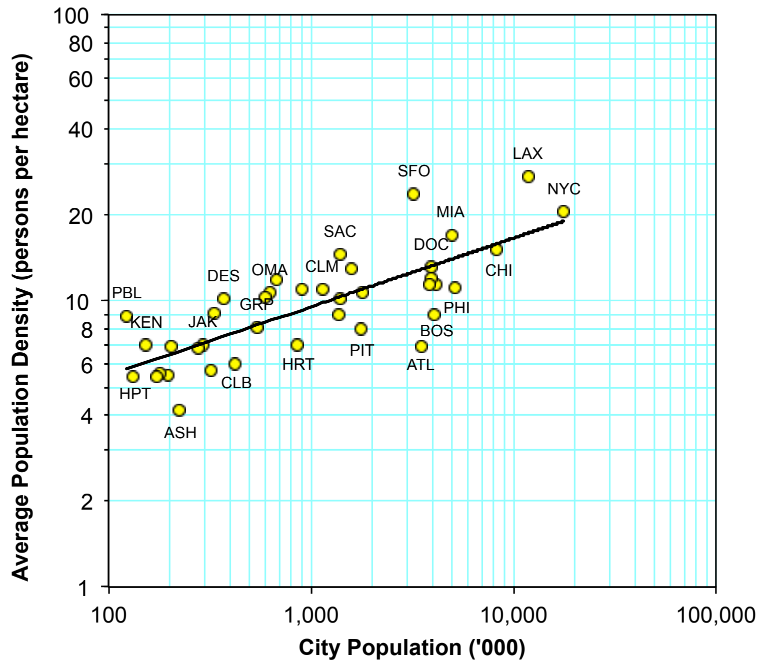

Figure 9: Average population density as a function of city population size in 40 U.S. metropolitan areas in 2000

3. Workers and workplaces in larger U.S. cities move closer together to remain within an acceptable commute 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).

Actual commuting distances in our sample of 40 U.S. cities—measured here as beeline distances between the centroid of a census tract containing a given commuter residence and the centroid of a census tract containing her workplace—increased only by a factor of 1.14 or by 14% when the population of a city doubled, slightly less than half the expected 30% increase as a result of densification. We can only ascribe the difference between the expected 30% increase in commuting distance and the actual 14% increase in that distance to the dynamic adaptation of metropolitan

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7 The power function shown in figure 8 for the city Area, A, measured in square kilometers, as a function of the city population, P, is $A = 0.029P^{0.76}$ $(R = 0.94)$, so that $A(2P) = 1.7A(P)$. The power function shown in figure 9 for the average population density in the city, D, measured in people per hectare, as a function of the city population, P, is $D = 0.35P^{0.24}$ $(R = 0.61)$, so that $D(2P) = 1.18D(P)$.

labor markets to increases in city size: The relocation of workers' homes to get closer to their actual jobs and the relocation of workplaces to get closer to their actual workers. Closer in the sense that if the area of a given city is twice that of a smaller one, average commute distance in that city will not increase by the expected square root of 2 but by a significantly smaller value. In other words, in the larger city a worker will have to be closer to her own job than to all other jobs taken together than a worker in a smaller one; and workplaces will have to be closer to their workforce than to the entire set of metropolitan workplaces. Or, put differently, a worker in the larger city will have to locate closer to her actual workplace—compromising her overall potential access to all other jobs in the city—than a worker in a smaller city. And a workplace in the larger city will have to locate closer to its actual workforce—compromising its overall potential access to the entire metropolitan labor pool—than a workplace in a smaller city.

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 distance or travel time to their job location (Getis, 1969). 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 than 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 commute range. Data from the U.S. Census Bureau for *intra-county* residential moves in 2008-2009 indeed confirms that only 8.9 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 (see table 1). Given the way the data is organized, we have no way of telling what share of intra-county or inter-county moves are within a single

Reason to Move	Percent
Family-Related Reasons	**26.5**
Change in marital status	5.5
To establish own household	11.6
Other Family reason	9.5
Employment Related Reasons	**8.9**
New job or job transfer	2.1
To look for work or lost job	1.0
To be closer to work/easier commute	5.0
Retired	0.2
Other job-related reasons	0.7
Housing-Related Reasons	**57.2**
Wanted to own home, not rent	6.6
Wanted new or better home/apartment	18.6
Wanted better neighborhood/less crime	6.2
Wanted cheaper housing	13.9
Other housing-related reason	11.9
Other Reasons	**7.5**
To attend or leave college	1.5
Change of climate	0.1
Health reason	1.4
Natural disaster	0.5
Other reason	4.1

Table 1:Reasons for Intra-County Move by Type of Move, 2008-2009

Source: U.S. Census, 2011. *Geographical Mobility 2008 to 2009*, P20-565, November, table 7, 16.

metropolitan area. We have reason to believe that most urban intra-county moves are within a single metropolitan area and that a substantial share of inter-county moves is also within a given metropolitan area. When we examine the data on inter-county moves for 2008-2009, we find that the longer the distance involved, the more important employment-related reasons become. Namely, when jobs are outside a worker's tolerable commute range, she is more likely to move, and the further the job, the more likely she is to move: While the share of employment-related reasons for intra-county moves in 2008-2009 was only 8.9%, that share increases to 19.2% for inter-country moves of less than 50 miles, to 43.8% for inter-county moves of 50 to 199 miles, to 54.0% for moves of 200-499 miles, and declined to 43.9% for inter-county moves of 500 miles or more (U.S. Census, 2011, figure 4, 17).

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 10. The graph in figure 10 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 (12.8 kms.) from their workplace increased their commute distance when they moved. When their original distance to work was more than 16 miles (25.6 kms.), more than two-thirds of commuters moved to places that were

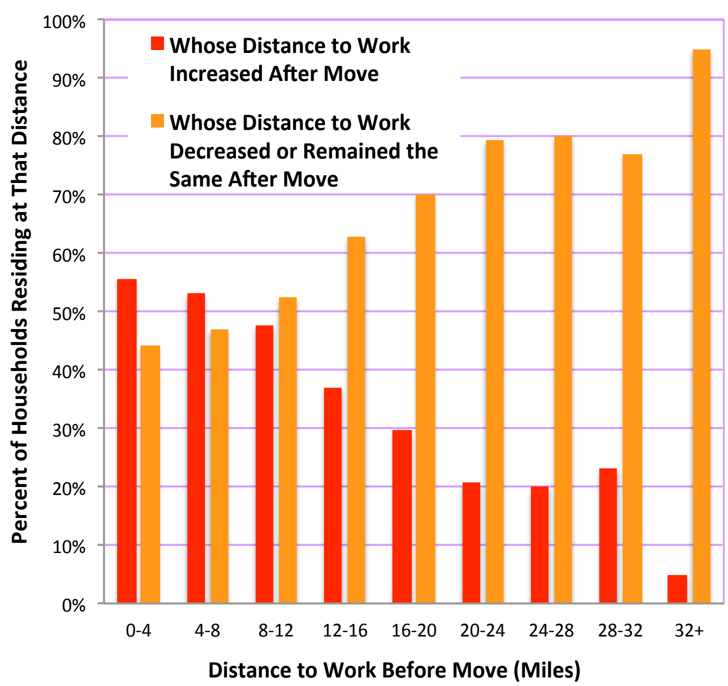

Figure 10: Changes in distance to work after residential moves for 462 households in the Seattle, WA, area, 1989-1997.

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

closer to their jobs. And of those that originally lived more than 32 miles (51.2 kms.) 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 a tolerable commute range, but they do move closer when their workplace are outside their tolerable commute range. In light of the findings in table 1, 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 a 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.

From the perspective of elementary geometry, there is no doubt that when cities grow in population and expand in area, both residences and workplaces disperse further and further away from the city center as well as away from each other. As we saw earlier, when city areas double, other things being equal, the average distance from random locations to the CBD and the average distance between random locations both increase by the square root of 2. And to keep the commuting distances and times between jobs and residences within workers' tolerable commute ranges, however defined, workplaces have to disperse into the urban periphery at similar or at higher rates than residences. Whether they do or not is an empirical question. As we shall see below, the evidence suggests that when workplaces decentralize and suburbanize, moving away from the CBD, they get closer to their workers rather than moving further away from them.

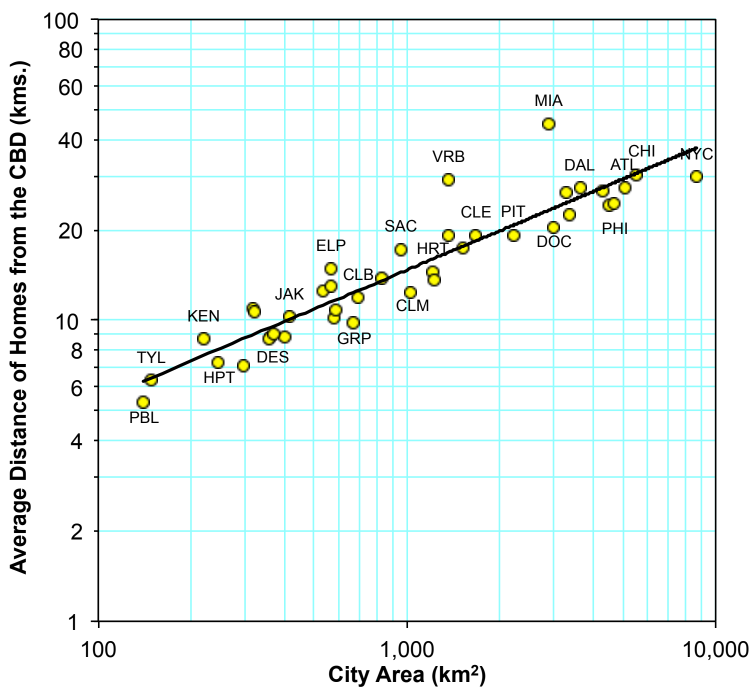

Figure 11: The average distance of commuter homes from the CBD as a function of city area in a sample of 40 U.S. cities in 2000

There are two simple metrics that can measure how decentralized residences in a given city are: (1) The *Average Distance of Homes from the CBD*;[8] and (2) The *Home Decentralization Index,* defined as the average distance of homes from the CBD divided by the average distance of homes from the CBD when homes are evenly distributed throughout the area of the city.[9] This second index attains the value of 0 when all homes are concentrated at a point in the CBD, and the value of 1 when homes are evenly distributed throughout the city. It can also attain a value greater than 1 if there are more homes in peripheral locations than in more central ones. These same two metrics, referring to job locations rather than to home locations, can also be used to define the *Average Distance of Jobs from the CBD* and the *Job Decentralization Index*. The values for these metrics for both the residences and jobs of commuters for the 40 U.S. cities in our sample plotted against their total area and their total population are displayed in figures 11-14.

In theory, as we noted earlier, when city areas doubled—if the relative distance among homes and among jobs remained the same—their decentralization indices would remain unchanged, and the average distance of both homes and jobs from the CBD should increase by a factor of $\sqrt{2}$ or by 41%. Figure 11 reveals that as city areas doubled, the actual average distance of commuter homes from the CBD increased by 35%, somewhat less than the expected 41%. The increase was systematic and statistically significant ($R^2 = 0.87$). Figure 12 shows that the average value of the Home Decentralization Index for all 40 cities in our sample was 0.87±0.03, quite close to 1, the value it would attain if residences were distributed evenly

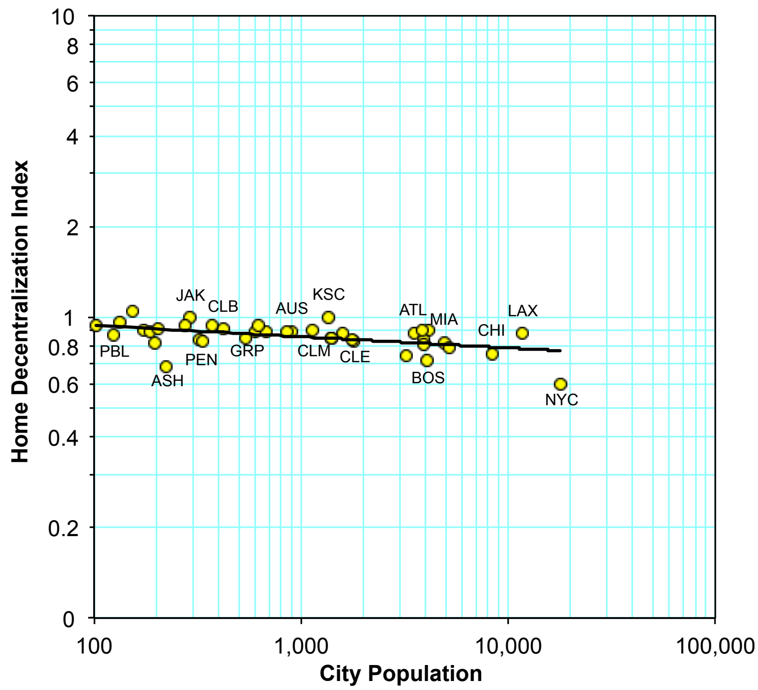

Figure 12: The Home Decentralization Index as a function of city population in a sample of 40 U.S. cities in 2000

8 The average distance of home locations from the CBD in a given city is the sum of the product [number of commuter trip destinations in a census tract x the distance of census tract centroid from the CBD] for all tracts, divided by the total number of trip destinations in the city.

9 The average distance of home locations from the CBD is calculated as before. The average distance of homes from the CBD when they are evenly distributed throughout the urban area in a given city is the sum of the product [the area of a census tract x the distance of census tract centroid from the CBD] for all tracts, divided by the total area of the city. The Home Decentralization Index is the ratio of the former and the latter values.

throughout the city.[10] The Index did decline systematically when city areas increased, but at a relatively slow rate. It decreased by 3.3% when city areas doubled and that increase was statistically significant at the 95% confidence level. This implies that residences in larger cities are significantly less decentralized than residences in smaller ones.

Figure 13 reveals that as a city area doubled, the average distance of job locations from the CBD increased by 39%, almost at the expected increase of 41%. The increase was systematic and statistically significant (R^2 = 0.81). Figure 14 shows that job locations in U.S. cities were not as decentralized as homes: The average value of the Job Decentralization Index was only 0.70±0.03, and the index barely declined at all when city area increased: it only declined by 0.4% when the city area doubled and that decline was not statistically significant.[11]

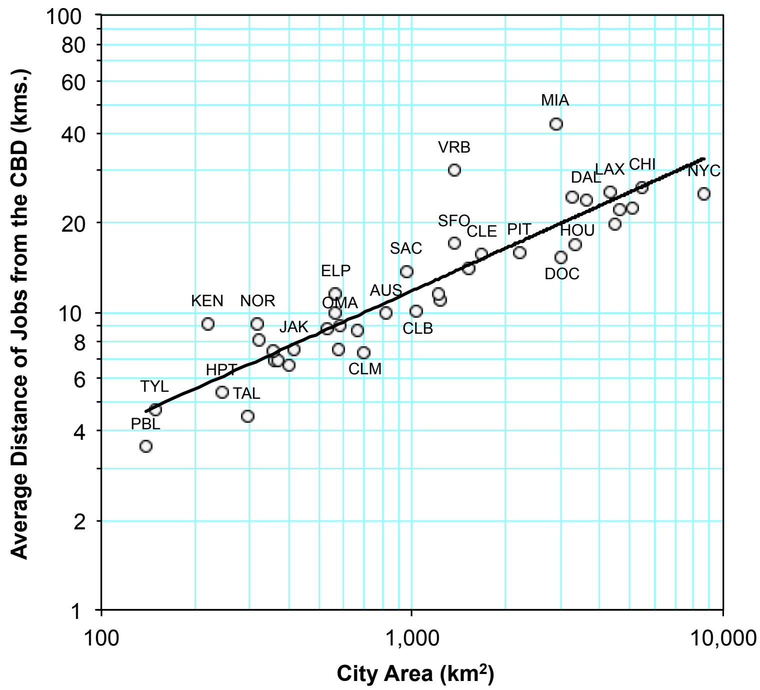

Figure 13: The average distance of jobs from the CBD as a function of city area in a sample of 40 U.S. cities in 2000

But when we consider that workplaces decentralize at a faster rate than homes when city areas increase—since, as we noted earlier, the average distance of jobs and homes from the CBD increased by 39% and 35% respectively when city areas doubled—we must conclude that workplaces in larger cities tend to move closer to homes. The comparison of figures 12 and 14 suggests that, because commuter homes are now more decentralized than job locations, when jobs are decentralizing at a somewhat faster rate than homes when cities grow and expand, they become closer in relative terms to homes.

Did the decentralization of jobs increase or decrease average commute distances? The empirical evidence regarding this question in the literature is inconsistent. Some researchers (e.g. Cervero

10 The power function shown in figure 11 for the average distance of homes from the CBD, D_H, measured in kilometers, as a function of the city area, A, measured in square kilometers, is $D_H = 0.74A^{0.43}$ $(R = 0.87)$, so that $D_H(2A) = 1.35D_H(A)$. The power function shown in figure 12 for the Home Decentralization Index, I_H, as a function of the city population, P, is $I_H = 0.35P^{0.24}$ $(R = 0.61)$, so that $I_H(2P) = 0.98I_H(P)$.

11 The power function shown in figure 13 for the average distance of jobs from the CBD, D_J, measured in kilometers, as a function of the city area, A, measured in square kilometers, is $D_J = 0.45A^{0.47}$ $(R = 0.81)$, so that $D_J(2A) = 1.39D_J(A)$. The power function shown in figure 14 for the Job Decentralization Index, I_J, as a function of the city population, P, is $I_J = 0.69P^{-0.0001}$ $(R = 0.00)$, so that $I_J(2P) = I_J(P)$.

and Landis, 1991; Levinson and Kumar, 1994; Naess and Sandberg, 1996; Cervero and Wu, 1998; Parolin, 2005; and Aguilera, 2005) find that decentralization increases both average commuting distances and average commuting times. Others (e.g. Giuliano, 1991; Giuliano and Small, 1993; and Guth, Holz-Rau and Maciolek, 2009) find that decentralization shortens average commuter distances. The evidence from our sample of 40 cities is unequivocal. The simple average distance of jobs from the CBD in the cities in the sample is 13.9±2.7 kilometers (with 95% confidence intervals), confirming that jobs in U.S. cities are now firmly decentralized. The average distance from homes in these cities to the CBD is 16.6±2.8 kilometers. This would be the average commute distance to jobs if all jobs were located in the CBD. But the actual average distance to jobs in our sample of cities is only 10.3±0.9 kilometers, namely significantly lower—indeed, less than two-thirds—than the hypothetical commute distance to the CBD if all jobs were concentrated there.[12] We must therefore conclude that by moving away from the CBD, workplaces have significantly shortened the commute distances of their employees. In fact, they shortened it, on average, by more than one-third.

As a result of the adjustments of both residence and workplace locations so as to be within a tolerable commuting range of each other, when city *areas* doubled, the actual *average beeline distance* between commuters' homes and their jobs did not increase by the expected 41% but by less than one-half that value. It increased only by 18%. This is illustrated in the top graph in figure 15, showing the average beeline commuting distance in a city as a function of its area. As the graph shows, the relationship between the two is very robust ($R^2 = 0.88$). In addition, as we noted earlier, when the *population* of a city doubled, its average density increased and, as a result, its area did not double; it increased, on average, only by 70%. When the two sets of adjustments are taken together, the factor by which commuting distance increased when the city population doubled is only 1.14 or 14%. This is illustrated in the bottom

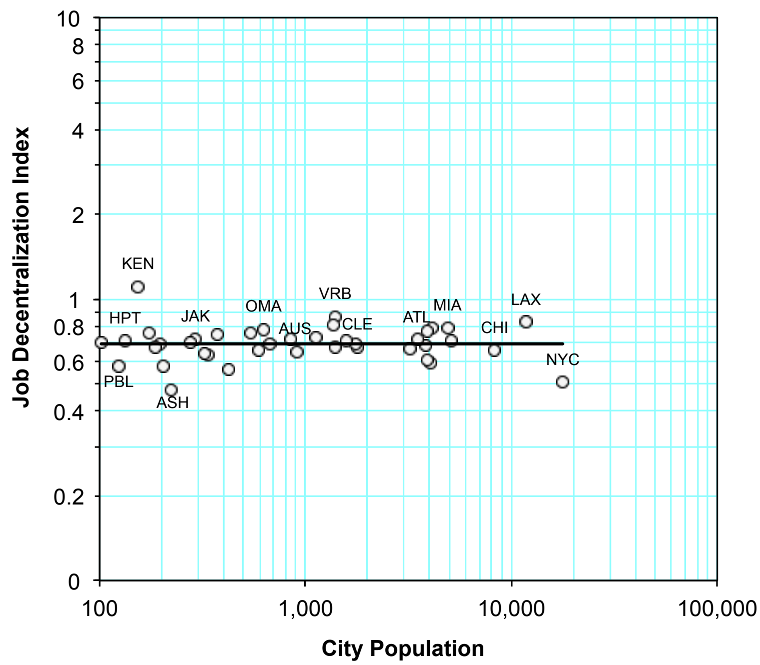

Figure 14: The Job Decentralization Index as a function of city population in a sample of 40 U.S. cities in 2000

12 Weighting these calculations by the number of commuters in each city in the sample results in an average job distance from the CBD of 21.8 kilometers and an average commuter home distance from the CBD of 25.2 kilometers. The actual weighted average distance to a job in the cities in the sample is 13.0 kilometers. Weighting increases the influence of cities with more commuters on the resulting averages.

graph in figure 15, showing the average beeline commuting distance in a city plotted against its population. As the graph shows, this relationship is also very robust ($R^2 = 0.80$).[13]

To conclude, commuters and workplaces both adjust their locations so as to be closer to each other or, more specifically so that their commuting distances—and hence their commuting times as well—remain within a tolerable commute range. As a result, when city areas double in size, the average distance between residences and workplaces does not increase by a factor of $\sqrt{2}$ or by 41% as expected, but only by 18%. This means that larger cities do not experience the large increase in commute distance that would be expected due to the increased distances among all locations when their areas, say, double in size. They experience only half the expected increase in commute distance and that allows them to increase the effective size of their labor markets and, as a consequence, to increase their productivity as well, as they grow in population and area.

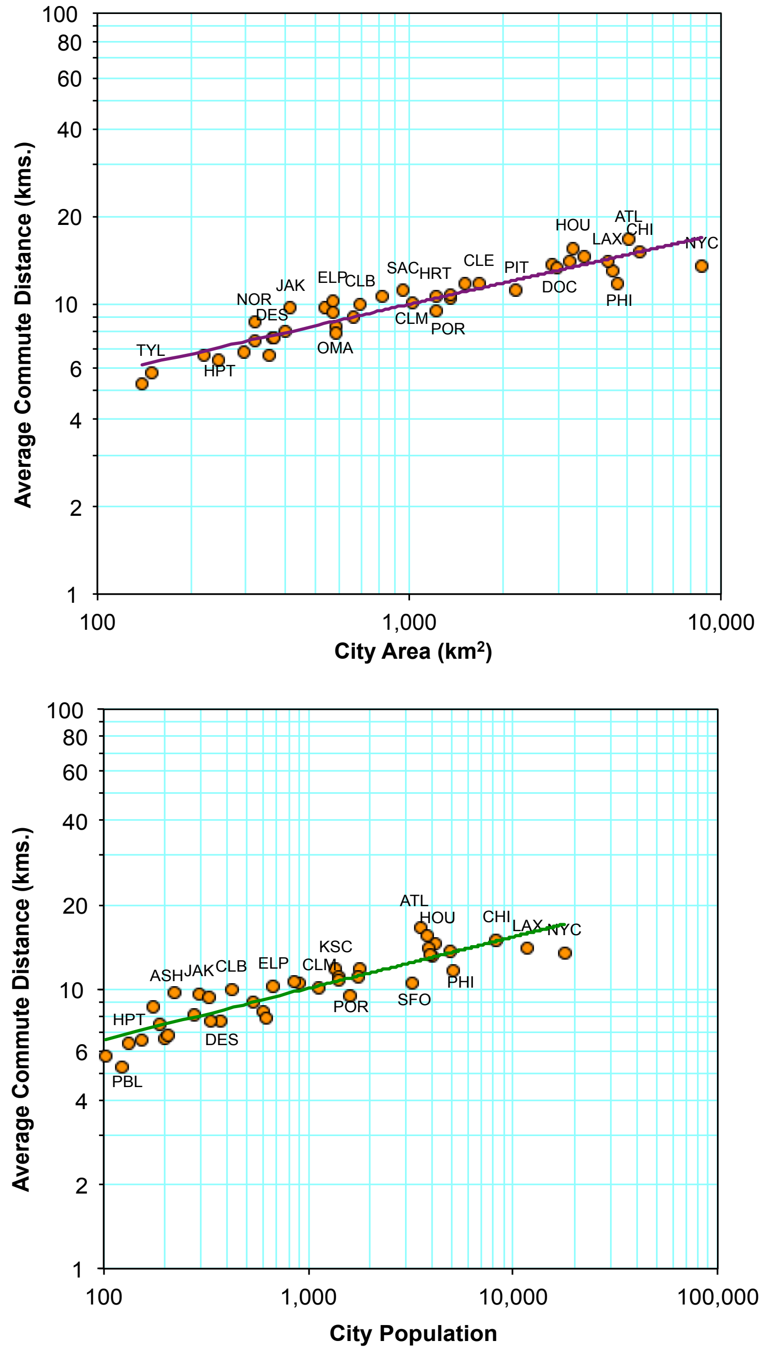

Figure 15: Average beeline commute distance as a function of city area (top) and city population (bottom) in a sample of 40 U.S. cities in 2000

13 The power function shown in figure 15 (top) for the average commute distance, *D*, measured in kilometers, as a function of the city area, *A*, measured in square kilometers, is $D = 1.85A^{0.24}$ *(R =0.88)*, so that $D(2A) = 1.18D(A)$. The power function shown in figure 15 (bottom) for the average commute distance, *D*, measured in kilometers, as a function of the city population, *P*, is $D = 0.79P^{0.18}$ *(R =0.80)*, so that $D(2P) = 1.14D(P)$.

4. Greater mobility: Commuters in larger cities travel at faster average speeds

The speed of an individual commuter on her way to work is the total distance covered by her trip—i.e. the sum total of the sidewalk, road, and rail segments she used—divided by the total time of her trip. The average commuting speed in a given city is thus the average speed of all its individual commuters. We were not able to obtain data on the actual distance traveled by individual commuters. But we did obtain data on the distribution of commuting times for commuters leaving a given census tract. We also obtained data on the share of commuters from that tract traveling to each census tract in the city, and thus on the distribution of beeline distances for all commuting trips leaving a given tract. We could thus calculate the average beeline speed for all commuting trips leaving a given tract, and the *average beeline speed* for all commuting trips in a given city as the weighted average of the average beeline commuting speeds from individual tracts. Although arrived at by separate calculations, the average commuting time in a city is approximately equal to its average beeline distance divided by its average beeline speed. The average beeline speed can thus be construed as a simple metric of the overall mobility in the city, the ease with which the transportation system in the city allows its workers to reach their workplaces.

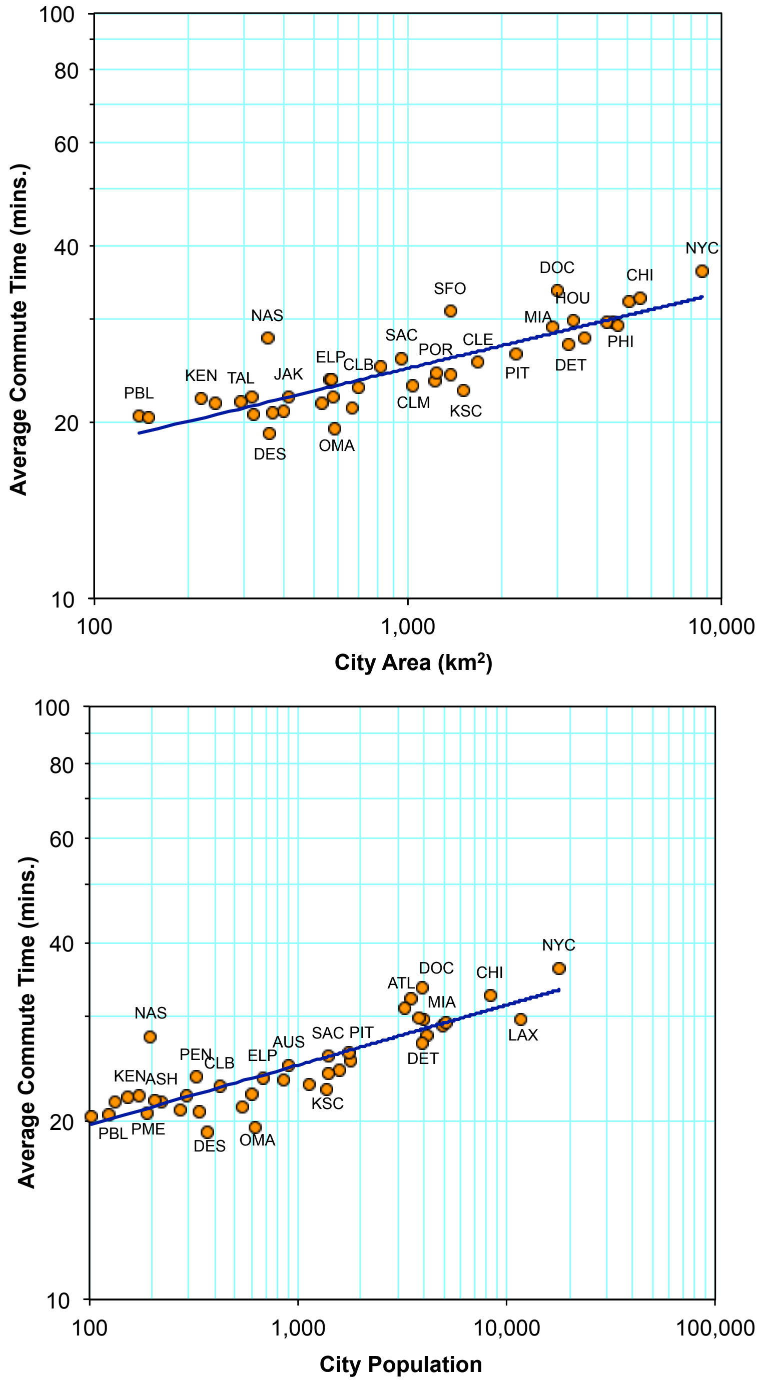

Figure 16: Average commuting time as a function of city area (top) and city population (bottom) in a sample of 40 U.S. cities in 2000

If we assume at the outset that when a city area doubles, average beeline speeds in the city remain the same, then average commuting time should increase by exactly the same proportion as the increase in average beeline distance, namely by 18%. And when the city population doubles, it should increase by 14%. If, for some reason, mobility in the larger city is impaired, commuting time should increase by more than 18% when the area doubles and by more than 14% when the city population doubles. Surprisingly, we find that in our sample of 40 U.S. cities in the year 2000, when city areas doubled, the average commuting time increased by a factor of 1.09, namely by 9%, only half the expected increase of 18%. This is illustrated in the top graph of figure 16, showing the average commuting time in a city as a function of its area. As the graph shows, this relationship is very robust (R^2 = 0.74). A similar result pertains to the doubling of the city population, illustrated in the bottom graph of figure 16: When the city population doubled, the average commuting time increased by a factor of 1.07, namely by 7%, only half the expected increase of 14%. As the graph shows, this relationship is very robust too (R^2 = 0.73).[14]

The fact that commuting times increase at a slower rate than commuting distances suggests that larger cities offer greater mobility—reflected in faster commuting travel speeds—than smaller ones. Indeed, our data confirm that this is indeed the case. Figures 17 displays the relationship between average commuting speed and the city area in our sample of 40 U.S. cities for the year 2000. It shows that when the area of a city doubled, average travel speed on the journey to work increased by 8%. The relationship is robust (R^2 = 0.45). Figure 18 displays the relationship between average commuting speed and city population in these cities. It shows that when the population of a city doubled, average travel speed on the journey to work increased by 6%. The relationship is also robust (R^2 = 0.38).[15] What these graphs make clear, and quite surprising, is that our common perception—often repeated in economic analyses of urban agglomeration economies—that

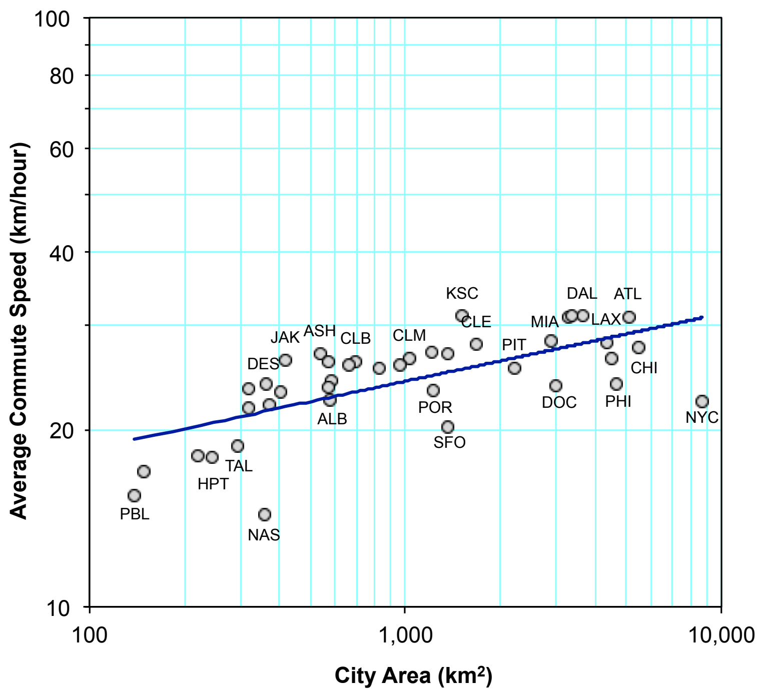

Figure 17: Average commuting speed as a function of city area in a sample of 40 U.S. cities in 2000

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14 The power function shown in figure 16 (top) for the average commute time, *T*, measured in minutes, as a function of the city area, *A*, measured in square kilometers, is $T = 10.1A^{0.13}$ *(R =0.74)*, so that *T(2A) = 1.09T(A).* The power function shown in figure 16 (bottom) for the average commute time, *T*, measured in minutes, as a function of the city population, *P*, is $T = 6.1P^{0.1}$ *(R =0.73)*, so that *T(2P) = 1.07T(P).*

15 The power function shown in figure 17 for the average commute speed, *V*, measured in kilometers per hour, as a function of the city area, *A*, measured in square kilometers, is $V = 10.93A^{0.115}$ *(R =0.45)*, so that *V(2A) = 1.08V(A).* The power function shown in figure 18 for the average commute speed, *V*, measured in

commuting in larger cities takes place at slower average speeds because of greater congestion on the roads appears to be wrong. Even though roads in larger cities may be more congested, when looking at all commuting trips taken together, commuter travel in larger cities is not slower, but faster, than commuter travel in smaller ones.

Part of the explanation for the ability of larger cities to keep congestion penalties at bay is that transportation infrastructure and traffic management in larger cities appears to keep up with their population growth and the expansion of their built-up areas. Road capacity in particular—and more specifically, the number of lane kilometers of freeways and arterial roads—increases sufficiently to accommodate the additional commuter traffic generated in larger cities by their larger populations commuting for longer distances.

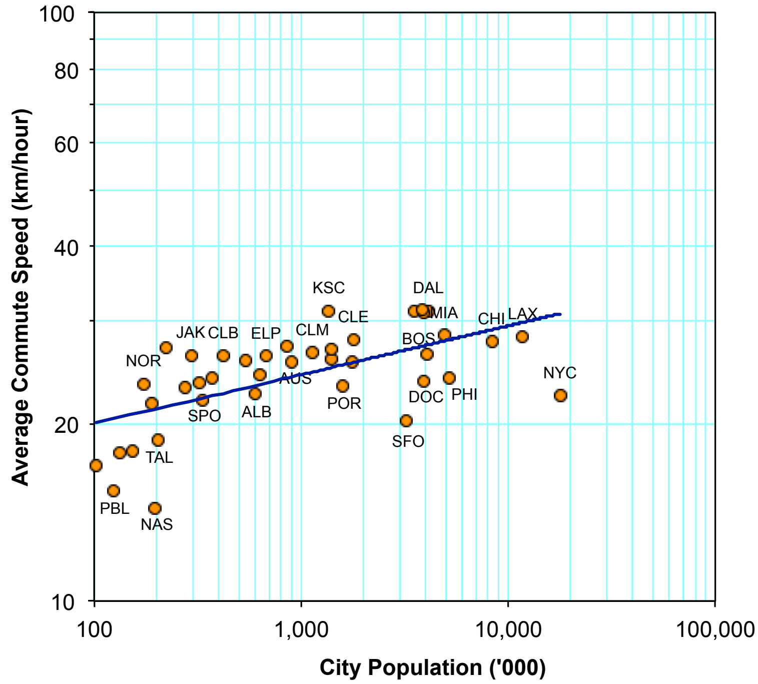

Figure 18: Average commuting speed as a function of city population in a sample of 40 U.S. cities in 2000

What is the expected increase in arterial road kilometers, for example, to maintain the same road density (number of lane kilometers per square kilometer of area) when a city area doubles? Figure 19 (left) shows a square city 10-by-10 kilometers in area and a total area of 100 square kilometers, with a grid of arterial roads, spaced 1-kilometer apart. The total length of the grid is 200 kilometers and, therefore, road density is 2kms./km². Now imagine a square city 20-by-20 kilometers in area and a total area of 400 square kilometers, with an arterial grid also spaced 1-kilometer apart (figure 19, right). It can be easily ascertained that the total length of the grid is this city is 800 kilometers and that, therefore, road density is 2 kms./km² as well. In this example, when city area

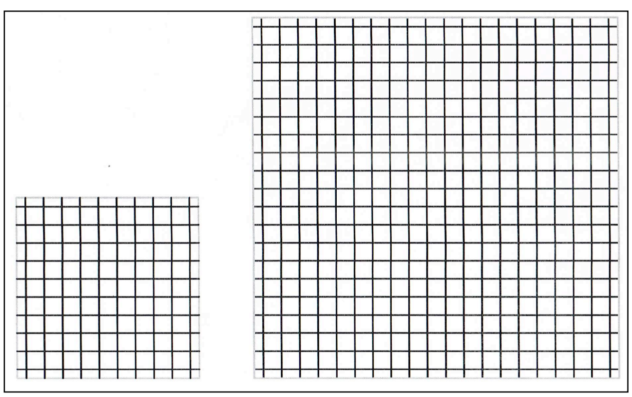

Figure 19: In a square city, the arterial grid quadruples in total length when city area quadruples

kilometers per hour, as a function of the city population, *P*, is $V = 7.7P^{0.083}$ *(R =0.38)*, so that *V(2P) = 1.06V(P)*.

quadrupled, the total length of arterial roads quadrupled as well. More generally, we can expect that when a city area doubles, for road density to remain the same, the total length of arterial roads must double as well. If the total length of arterial road lanes more than doubles—and the width of arterial roads does not change—then we can conclude that there are more arterial roads in the city and that they are spaced closer together, namely that road density increased.

Data for 106 U.S. cities in 2011 (Shrank, Eisele and Lomax, 2012) confirms that the number of freeway and arterial road lane kilometers increases at a faster-than-expected rate when city area increases (figure 20). When city areas doubled, for example, arterial road lane kilometers increased by a factor of 226% and freeway lane kilometers increased by 233%. Those increases were both statistically significant (*R^2 = 0.91* and *R^2 = 0.82* respectively).[16]

If freeway lane kilometers increased by 233% when city areas doubled, then freeway lane density increased by a factor of 1.16 (2.33/2 = 1.16). If we assume that freeways were not widened to include more lanes, this implies that the average distance between freeways declined by a factor of $\sqrt{1.16}$ = 1.08, i.e. by 8%, when city areas doubled. The total amount of lane

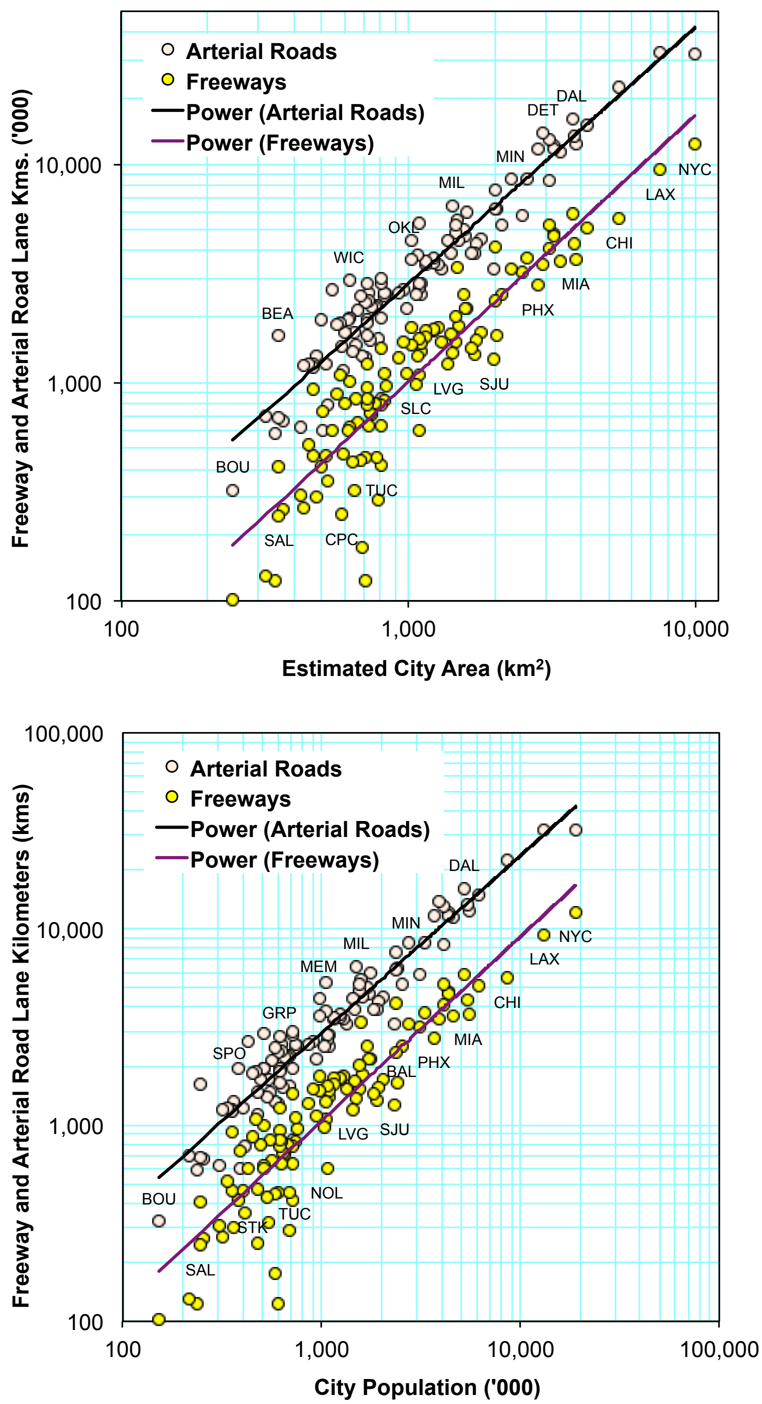

Figure 20: The number of lane kilometers of freeways and arterial roads as a function of city area (top) and city population (bottom) in 106 U.S. cities in 2011

16 The power function shown in figure 20 (top) for total arterial road lane length, L_A, measured in kilometers, as a function of the city area, A, measured in square kilometers, is $L_A = 0.84A^{1.18}$ *(R =0.91)*, so that $L_A(2A) = 2.26L_A(A)$. The power function for total freeway lane length, L_F, measured in kilometers, as a function of the city area, A, is $L_F = 0.22A^{1.22}$ *(R =0.82)*, so that $L_F(2A) = 2.33\ L_F(A)$.

kilometers of arterials roads increased by 226% when city areas doubled, i.e. arterial road lane density increased by a factor of 1.13 (2.26/2). Again, if we assume that arterial roads were not widened either, this implies that the average distance between arterial roads declined by a factor of $\sqrt{1.13}$ = 1.06, i.e. by 6%, when city areas doubled. We also observe that the density of freeways increased at a faster rate than the density of arterial roads when city areas doubled. On the whole, therefore, we can say that transportation infrastructure capacity in U.S. cities—measured simply as the availability, or more precisely the density, of freeways and arterial roads—increased at a faster rate than the increase in city area, so that road capacity was more plentiful in cities with larger areas than in cities with smaller ones.

We must recall, however, that when city areas double, their population densities increase by a factor of 1.18 (figure 9), a factor that is larger than the factors by which the lane densities of freeways or arterial roads increase. We must conclude, therefore, that lane kilometers of freeways or arterials roads do not quite double when city *populations* double. This is clearly observed in the graph on the bottom of figure 20. The graph shows that when city populations doubled, lane kilometers of freeways increased by 92% and lane kilometers of arterial roads increased by 87 %. Those increases were both statistically significant ($R^2 = 0.82$ and $R^2 = 0.91$ respectively).[17] That means that the amount of freeway lane kilometers per capita declined by a factor of 1.04 or by 4% when city populations doubled. The corresponding decline of arterial road lane kilometers per capita was 7%. All in all, although road density in larger cities increased, it did not increase at a rapid enough rate to allow for the increase in population density. Hence, we can conclude that freeways and arterial roads in cities with larger populations served more people and thus carried more traffic and were likely to be more congested than roads in cities with smaller populations.

It is no wonder, therefore, that peak period observed travel speeds on freeways and arterial roads decline regularly, albeit very slowly, when city populations increase. This is illustrated with data on 101 U.S. cities in the 2012 *Urban Mobility Report* presented in the top graph of figure 21. The graph shows that when a city doubled its population, peak period observed travel speeds on freeways declined by 2.3%, and on arterial roads by 1.5%.[18] That said, speeds were still considerably higher on freeways than on arterial roads. The average freeway speed during peak periods in the cities studied was 91.7±1.1 kilometers per hour, some 63% higher than the speed observed on arterial roads, 56.4±1.0 kilometers per hour.

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17 The power function shown in figure 20 (bottom) for total arterial road lane length, L_A, measured in kilometers, as a function of the city population, P, is $L_A = 0.0114P^{0.9}$ $(R = 0.91)$, so that $L_A(2P) = 1.87L_A(P)$. The power function for total freeway lane length, L_F, measured in kilometers, as a function of the city population, P, is $L_F = 0.025P^{0.94}$ $(R = 0.82)$, so that $L_F(2P) = 1.92L_F(P)$.

18 The power function shown in figure 21 (top) for the peak period observed travel speed on freeways, V_F, measured in kilometers per hour, as a function of the city population, P, is $V_F = 146.5P^{-0.034}$ $(R = 0.23)$, so that $V_F(2P) = 0.977V_F(P)$. The power function for the peak period observed travel speed on arterial roads, V_A, measured in kilometers per hour, as a function of the city population, P, is $V_A = 76.2P^{-0.022}$ $(R = 0.06)$, so that $V_A(2P) = 0.985V_A(P)$.

So why did we observe that overall commuting speeds in larger cities are faster? The reason that average commuting speeds in larger cities are faster than those in smaller ones can be explained by the shift from arterial road travel to freeway travel in larger cities. This is illustrated in the bottom graph in figure 21. As the graph shows, when city populations double in size, the daily vehicle kilometers per lane kilometer of freeway increased by 13%, while that of arterial roads increased by only 5%.[19] In other words, freeways carried a larger share of traffic at faster speeds. More generally, we can say that as cities grow in population, roads that are further up in the transport hierarchy carry a larger share of commuter traffic, and they carry it at faster speeds. A smaller share of trips use slower local and arterial roads and a higher share of trips uses the faster freeways. It is for this reason that we observed earlier that the overall average speed of commuter trips increased by 8% when city area in our sample doubled.

To summarize this entire section, in our analysis of a stratified sample of 40 U.S. metropolitan areas in 2000 and associated traffic data from 2011 we found that when the population of cities doubled, their population densities increased, on average, by 18%. As a result, their urbanized areas did not double; they increased only by 70%.

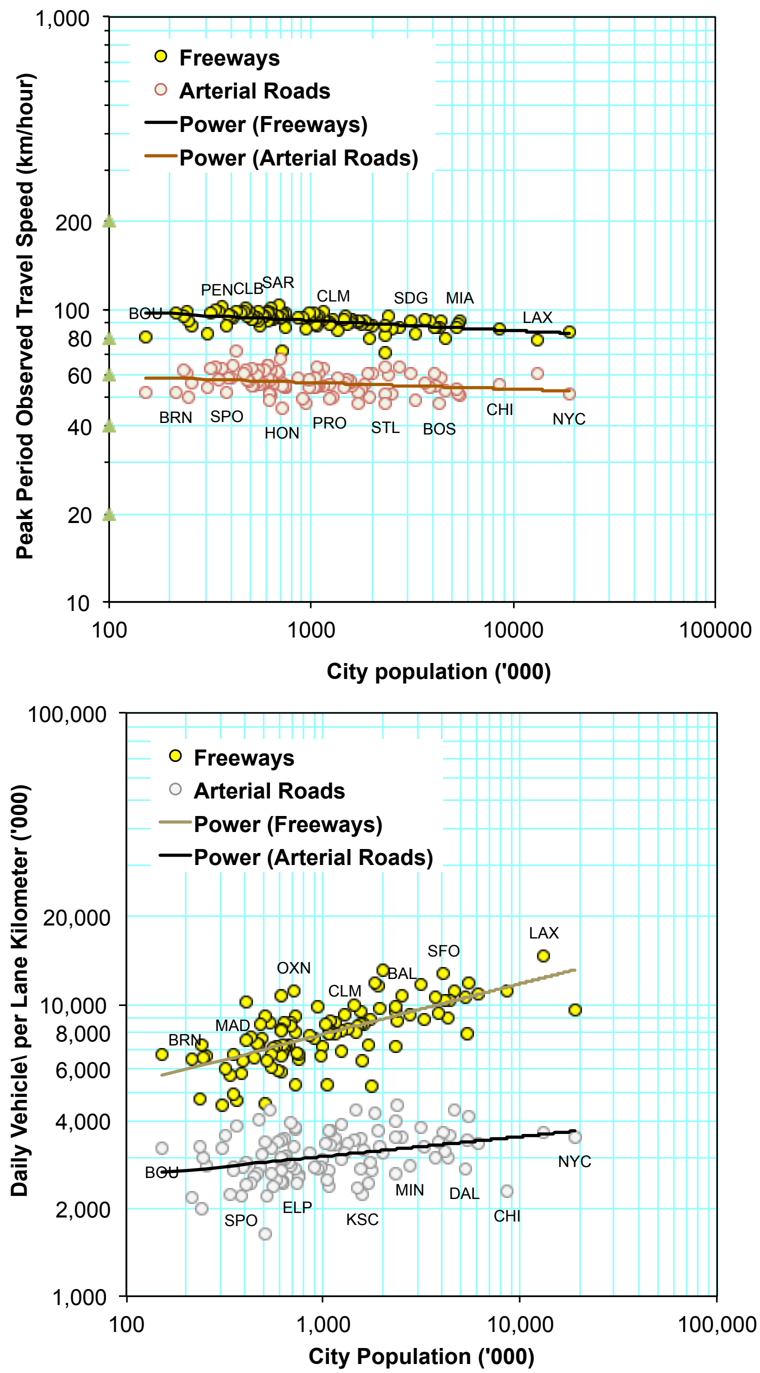

Figure 21: Peak period observed travel speeds (top) and daily vehicle per lane kilometer on freeways and arterial roads (bottom) as functions of city population size in 106 U.S. cities in 2011

19 The power function shown in figure 21 (bottom) for daily vehicles per lane kilometer on freeways, K_F, as a function of the city population, P, is $K_F = 722.1P^{0.17}$ ($R = 0.46$), so that $K_F(2P) = 1.13K_F(P)$. The power function for daily vehicles per lane kilometer on arterial roads, K_A, as a function of the city population, P, is $K_A = 1175.2P^{0.068}$ ($R = 0.11$), so that $K_A(2P) = 1.05K_A(P)$.

Therefore, the average commuting distance—expected to increase by a factor of $\sqrt{2}$ —increased only by a factor of $\sqrt{1.7}$ =1.3, namely by 30% instead of by 41%. Observed average commuting distance in our sample of cities increased by only 14% when the city population doubled, rather than by an expected 30%—because homes and workplaces throughout the metropolitan area relocated to get within an acceptable commute range of each other. Finally, when city areas doubled, average commuting speeds increased by an average of 8%. The compounded result of all these three adjustments—densification, relocation, and increased mobility—was that commuting time in larger cities rose only by 7% instead of increasing by the expected 41% when city populations doubled. This less-than-expected rise in commuting time is the key reason why metropolitan labor markets in American cities were able to grow almost in direct proportion to their population, as we saw earlier, and that is why American cities were able to increase their productivity as they increased in size.

Conclusion: The Policy Implications of the Study

Given the productivity advantages of large, integrated metropolitan labor markets, the policy implications of these findings are clear. Urban transportation and land use planners and policy makers who are committed to fostering and maintaining the productivity of large metropolitan areas need to focus on facilitating commuting travel in the metropolitan area as a whole. Not just on commuting to the central city, and not just on short commutes within the small self-governing cities and neighborhoods that make up the metropolitan area, but on commuting in the metropolitan area as a whole. Why? Because one of the most important economic advantages of a metropolitan area—if not its most important one—is the size of its labor market or, more precisely, the overall *access* of its labor to the jobs it offers: the access of firms to the largest possible pool of workers and the access of workers to the largest possible pool of jobs. Not its overall mobility necessarily, but the overall mobility of its labor to its jobs. Commuting may take up slightly more than one-quarter of all personal vehicle miles travelled (data for 2009, AASHTO 2013, table 2.1, 9), but it is that quarter which drives the metropolitan economy.

A simple metric to measure the overall access to jobs of a given metropolitan labor market is the share of residence-workplace pairs that are within an agreed-upon acceptable commute range. That range can vary from commuter to commuter and from city to city. It can be as high as 60 minutes or as low as 30 minutes: "One characteristic people have shown that has been important in shaping the nature of our cities is that they do not like to commute, on average, more than half an hour to major urban destinations. In the United Kingdom, a government study found that travel time for work trips has been stable for six centuries" (Newman and Kenworthy 1999, 37). In fact, the weighted average commuting time for our sample of 40 U.S. cities in 2000 was still 30 minutes.

A simple land use policy goal that can and will foster economic development in cities large and small is to *maintain or increase the number of residence-workplace pairs that are within an agreed-upon commuting range of each other*. The impact of alternative policies, programs and projects on attaining that goal can be simulated and then evaluated by their relative cost of bringing *one* residence-workplace pair within that agreed-upon commuting range of one another, and not necessarily any closer. More targeted programs, say those focusing on reducing unemployment or underemployment in poor central city neighborhoods or on improving housing affordability, can be simulated and evaluated on the same basis: their relative cost of bringing one residence-workplace pair within a tolerable commute range.

This goal may be achieved in two complementary metropolitan land use policies. First, by facilitating residential mobility and opening up the entire metropolitan housing market—through zoning and land use regulations, real estate taxes, subsidies for affordable housing, policies that facilitate real estate transactions, or fair share arrangements—to ensure that workers can always relocate to appropriate and affordable residences within a tolerable commute range of the jobs they can and want to fill. Second, by allowing firms—through zoning, land use, and environmental regulations, taxes and subsidies, or infrastructure provision—to locate throughout the metropolitan area, within an acceptable commute range of any worker pool they may want to attract.

A simple transportation policy goal that will maintain and increase the productivity of American cities is a renewed emphasis on maintaining and increasing the mobility of workers throughout the metropolitan area: developing and maintaining fast and efficient regional transportation systems that can connect *all* locations within a metropolitan area to *all* other locations. This necessarily requires a renewed emphasis on longer, rather than on shorter commutes, and on suburb-to-suburb commutes—journeys to work that now comprise the great majority of commuter travel—rather than commutes to the city center. And since, as we noted earlier, larger metropolitan areas may require, on average, longer commuting distances between residences and workplaces, they can only maintain that goal by ensuring that commuting takes place at higher average speeds. In other words, other things being equal, larger metropolitan areas require better metro-wide transportation infrastructure and better metro-wide traffic management than smaller ones, allowing commuters to travel longer distances at higher average speeds so as to maintain comparable overall access to their labor markets.

As it turns out, cities in general and large cities in particular are self-organizing. The efficiency with which metropolitan labor markets arrange and rearrange themselves so that jobs remain within workers' tolerable commute range and so that workers can continue to reach their workplaces quickly as cities grow larger and larger is not the result of *planning*. It comes about through the many location and travel decisions of workers seeking to improve their economic well-being and firms seeking to improve their profitability, given the range of locations and travel possibilities that the city offers or denies them. Transportation and land use policies can and do make possible the efficient and equitable operation of metropolitan labor markets, but they can also hinder and damage it.

To the extent that policy makers respond to the demand for metro-wide distribution of housing and residential land where this demand manifests itself, to the extent that they facilitate metro-wide residential mobility, to the extent that the respond to the metro-wide demand for business locations where this demand manifests itself, and to the extent that they respond to the demand for metro-wide travel where it is needed to get commuters from their actual residences to their actual workplaces quickly and cheaply, to that extent they indeed help metropolitan labor markets become more efficient and more equitable, and to that extent they make cities more productive. To the extent that they prevent or hinder workers from moving and relocating so as to be within their tolerable commute range to jobs throughout the metropolitan area, to the extent that they prevent the supply of affordable housing within workers' tolerable commute ranges to the best jobs they can find, to the extent that they prevent or hinder businesses from locating within tolerable commuting range of their actual and potential workers, and to the extent that they readily provide speedy transportation where it is not needed while failing to provide it where it is needed, to that extent they hinder and damage the performance of metropolitan labor markets and impede the economic performance of metropolitan areas.

* * *

Annex: 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 those of 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 22).

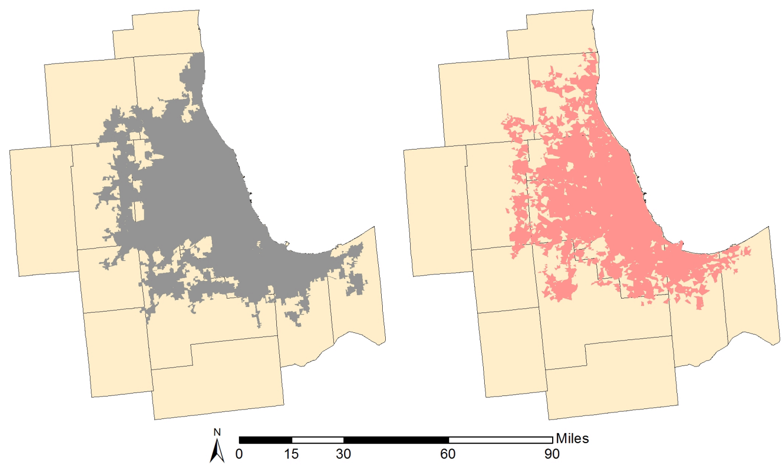

Figure 22. Thirteen counties comprising Chicago's MSA (yellow), Chicago's Urbanized Area in 2000 (grey) on left, and Chicago's built-up area in 2000 (red) identified by the *Modis 500 urban land cover map,* on right

Figure 22 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 242 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 23. 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

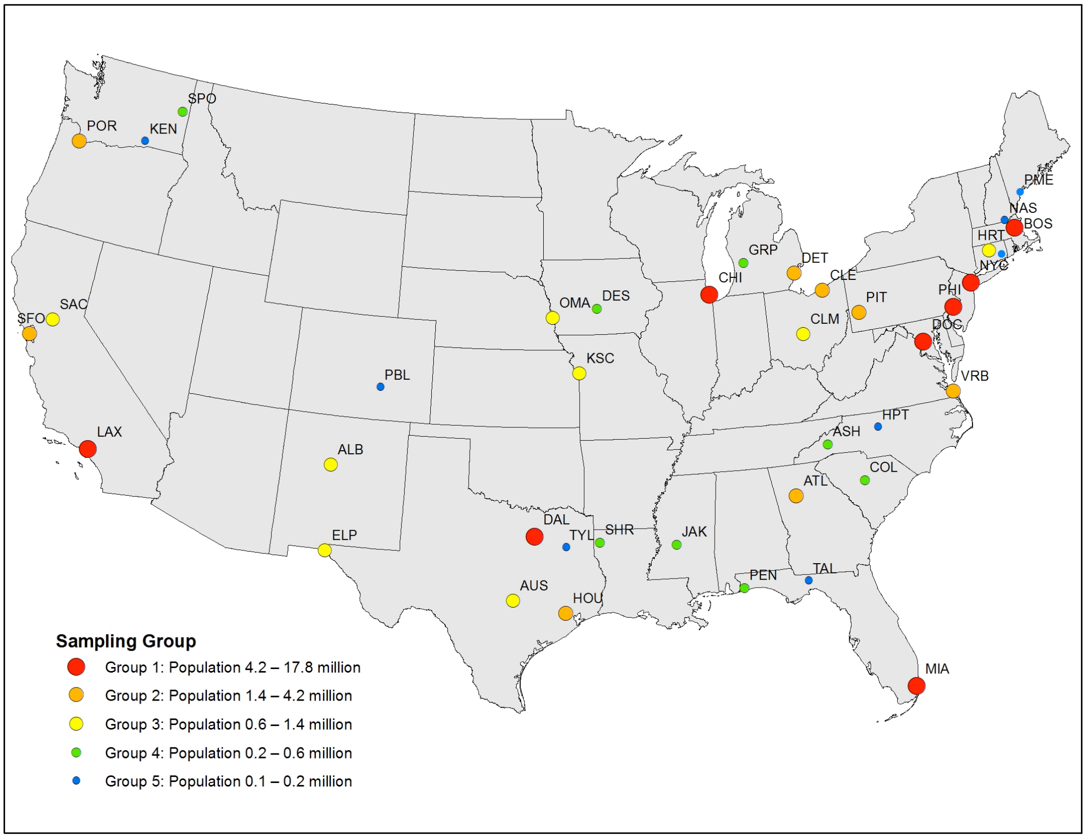

Figure 23: Locations of the 40 cities in the sample

3. Travel time, travel flow, and travel distance data

The nationwide travel time and commute flow data used in this analysis is reported at the census tract level. Travel times for both residences (home-based) and workplaces (work-based) in each census tract were extracted from the Census Transportation Planning Package (CTPP) *Part 1 - Place of Residence*, and *Part 2 - Place of Work* datasets for the year 2000, respectively. Travel times are self-reported, in minutes, and are likely to contain some degree of error. Unlike journey-to-work flows that allow for the analysis of tract-to-tract pairs, the reporting of travel time data by the Census does not provide, nor allow for, estimation of average tract-to-tract travel times. Rather, the travel times for home and work tracts are the weighted average of all reported home- and work-based commuting trips. More precisely, the CTPP reports the distribution of travel times for home-based and work-based trips in travel time bins of four-minute increments for trips under 60 minutes, bins of 15-minute increments for trips between 60 and 90 minutes, and a single bin for trips more than 90 minutes. Weighted travel time calculations were made using the mid-point value of the travel time bin. Trips belonging to the over-90-minute category were assigned a default value of 120 minutes.

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

Travel flows are based on the 2000 CTPP *Part III Journey-to-Work* dataset containing commuting flows between home and work census tracts. The data set contains information for 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 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. Average commute trip distances leaving home tracts or entering workplace tracts were calculated as the average of trip distances weighted by flows.

4. Metropolitan Statistical Area (MSA) and Texas Transportation Institute (TTI) labels

Figures 1 and 2 in the article display relationships between 347 Metropolitan Statistical Areas (MSAa) and measures of Gross Domestic Product (GDP). Table 4, below, contains only the three-letter labels shown in the figures, the MSA name, and the states they cross.

Label	Metropolitan Statistical Area	State(s)	Label	Metropolitan Statistical Area	State(s)
ABY	Albany-Schenectady-Troy	NY	MIA	Miami-Fort Lauderdale-West Palm Beach	FL
ANC	Anchorage	AK	NOL	New Orleans-Metairie	LA
ATL	Atlanta-Sandy Springs-Roswell	GA	NYC	New York-Newark-Jersey City	NY-NJ-PA
BOS	Boston-Cambridge-Newton	MA-NH	OMA	Omaha-Council Bluffs	NE-IA
BOU	Boulder	CO	PEN	Pensacola-Ferry Pass-Brent	FL
BRN	Brownsville-Harlingen	TX	PHI	Philadelphia-Camden-Wilmington	PA-NJ-DE-MD
BUF	Buffalo-Cheektowaga-Niagara Falls	NY	PHX	Phoenix-Mesa-Scottsdale	AZ
CHI	Chicago-Naperville-Elgin	IL-IN-WI	PRO	Providence-Warwick	RI-MA
DAL	Dallas-Fort Worth-Arlington	TX	RIV	Riverside-San Bernardino-Ontario	CA
DEN	Denver-Aurora-Lakewood	CO	SAN	San Antonio-New Braunfels	TX
DOC	Washington-Arlington-Alexandria	DC-VA-MD-WV	SEA	Seattle-Tacoma-Bellevue	WA
HRT	Hartford-West Hartford-East Hartford	CT	SFO	San Francisco-Oakland-Hayward	CA
JVL	Jacksonville	FL	SJO	San Jose-Sunnyvale-Santa Clara	CA
LAR	Laredo	TX	SLC	Salt Lake City	UT
LAX	Los Angeles-Long Beach-Anaheim	CA	STK	Stockton-Lodi	CA
MAD	Madison	WI	STL	St. Louis	MO-IL
MCA	McAllen-Edinburg-Mission	TX	TMP	Tampa-St. Petersburg-Clearwater	FL
			TUC	Tucson	AZ

Table 4. Metropolitan Statistical Areas (MSAs) labels in Figures 1 and 2

Figures 20 and 21 in the article show relationships between Urbanized Areas and mobility measures contained in the Texas Transportation Institute (TTI) Urban Mobility Report. A number of the three letter labels in these figures refer to Urbanized Areas that are not part of our 40-city sample. A list of these labels and the corresponding names and states is shown below in Table 5.

Label	Urbanized Area	State(s)	Label	Urbanized Area	State(s)
BEA	Beaumont	TX	NOL	New Orleans	LA
BOU	Boulder	CO	OXN	Oxnard	CA
BRN	Brownsville	TX	PHX	Phoenix-Mesa	AZ
CPC	Cape Coral	FL	PRO	Providence	RI-MA
HON	Honolulu	HI	SAL	Salem	OR
LVG	Las Vegas	NV	SAR	Sarasota-Bradenton	FL
MAD	Madison	WI	SDG	San Diego	CA
MEM	Memphis	TN-MS-AR	SJU	San Juan	PR
MIL	Milwaukee	WI	SLC	Salt Lake City	UT
MIN	Minneapolis-St. Paul	MN	STK	Stockton	CA

Table 5. Texas Transportation Institute (TTI) Urbanized Area labels not in the 40-city sample

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References

Aguilera, A., 2005. 'Growth in Commuting Distances in French Polycentric Metropolitan Areas: Paris, Lyon and Marseille', Urban Studies, vol. 42, no. 9, pp. 1537–1547.

Angel, Shlomo, 2012. *Planet of Cities,* Cambridge MA: Lincoln Institute of Land Policy.

Bertaud, A., 2004. 'The Spatial Organization of Cities: Deliberate Outcome or Unforeseen Consequence?', online at: http://alainbertaud.com/wp-content/uploads/2013/06/AB_The_spatial_organization_of_cities_Version_31.pdf.

Brown, H., 1975. 'Changes in workplace and residential locations', *Journal of the American Institute of Planners* 41, 32–39.

Cervero, R. and J. Landis, 1991. 'Suburbanization of Jobs and the Journey to Work,' Department of City and Regional Planning, University of California at Berkeley, Berkeley, CA.

Cervero, R. and K.-L. Wu, 1998. 'Sub-centering and Commuting: Evidence from the San Francisco Bay Area, 1980-90', Urban Studies, vol. 35, no. 7, pp. 1059-1076.

Cervero, R., 1996. 'Mixed Land-Uses and Commuting: Evidence from the American Housing Survey', Transportation Research Part A: Policy and Practice, vol. 30, no. 5, pp. 361-377.

Ciccone, A. and R. E. Hall, 1996. 'Productivity and the Density of Economic Activity,' *American Economic Review,* 86(1), 54–70.

Coles, M. G. and E. Smith. 1998. 'Marketplaces and Matching,' *International Economic Review,* 39(1), 239–255.

Combes, P.-P., G. Duranton, L. Gobillon, D. Puga, and S. Roux. 2009. 'The Productivity Advantages of Large Cities: Distinguishing Agglomeration from Firm Selection,' Discussion Paper 7191, Centre for Economic Policy Research.

Davis, K., 1972. *World Urbanization 1950-1970 Volume II; Analysis of Trends, Relationships and Development*, Population Monograph Series 9, University of California, Berkeley: Institute of International Studies.

Desmet, K. and M. Fafchamps. 2005. 'Changes in the Spatial Concentration of Employment Across US Counties: A Sectoral Analysis 1972–2000,' *Journal of Economic Geography,* 5(3), 261–284.

Dieleman, FM, Dijst, M & Burghouwt, G 2002, 'Urban Form and Travel Behaviour: Micro-level Household Attributes and Residential Context', Urban Studies, vol. 39, no. 3, pp. 507-527.

Dubin, R 1991, 'Commuting Patterns and Firm Decentralization', Land Economics, vol. 67, no. 1, pp. 15-29.

Duranton, G. 1998. 'Labor Specialization, Transport Costs, and City Size,' *Journal of Regional Science,* 38(4), 553–573.

Duranton, G. and D. Puga, 2004. 'Micro-Foundations of Urban Agglomeration Economies,' in V. Henderson and J.-F. Thisse (eds.), *Handbook of Regional and Urban Economics,* Vol. 4. Amsterdam: North-Holland, pp. 2063–2117.

Fujita, M, Krugman, PR & Venables, AJ 2001, *The Spatial Economy: Cities, Regions and International Trade*, MIT Press, Cambridge, MA.

Getis, A., 1969. 'Residential Location and the Journey from Work', *Proceedings of the Association of American Geographers* 1:55-59.

Giuliano, G & Small, KA 1993, 'Is the Journey to Work Explained by Urban Structure?', Urban Studies, vol. 30, no. 9, pp. 1485-1500.

Giuliano, G 1991, 'Is Jobs-Housing Balance a Transportation Issue?', Transportation Research Record, no. 1305, pp. 305-312.

Gordon, P & Richardson, HW 1997, 'Are Compact Cities a Desirable Planning Goal?', Journal of the American Planning Association, vol. 63, no. 1, pp. 95-106.

Gordon, P & Wong, HL 1985, 'The Costs of Urban Sprawl: Some New Evidence', Environment and Planning A, vol. 17, no. 5, pp. 661-666.

Gordon, P, Kumar, A & Richardson, HW 1989, 'The Influence of Metropolitan Spatial Structure on Commuting Time', Journal of Urban Economics, vol. 26, no. 2, pp. 138-151.

Gordon, P, Richardson, HW & Jun, M-J 1991, 'The Commuting Paradox Evidence from the Top Twenty ', Journal of the American Planning Association, vol. 57, no. 4, pp. 416-420.

Gordon, P. and Richardson, H. W., 1991. 'The Commuting Paradox', *Journal of the American Planning Association* 57(4), 416-20.

Guth, D., C. Holz-Rau, and M. Maciolek, 2009. 'Employment Suburbanisation and Commuter Traffic in German City Regions', 9th Swiss Transport Research Conference, Ascona, September 9-11.

Huxley, A., 1958. *Brave New World Revisited*, New York. Harper and Brothers Company.

Jun, M.-J., 2000. 'Commuting Patterns of New Town Residents in the Seoul Metropolitan Area ', Journal of the Korean Regional Development Association, vol. 12, no. 2, pp. 157-170.

Levinson, D. and A. Kumar, 1994. 'The Rational Locator: Why Travel Times Have Remained Stable', Journal of the American Planning Association, vol. 60, no. 3, pp. 319-332.

Litman, T. A., 2014. 'The Mobility-Productivity Paradox: Exploring The Negative Relationships Between Mobility and Economic Productivity', paper presented at the International Transportation and Economic Development Conference, 12 March, Victoria Transport Policy Institute, online at: http://www.vtpi.org/ITED_paradox.pdf.

Lucas, R. E., Jr. and E. Rossi-Hansberg. 2002. 'On the Internal Structure of Cities,' *Econometrica,* 70(4), 1445–1476.

Ma, Q., W. Zhang, and X. Wang, 2004. 'Review on Spatial Structure of The Metropolis Affecting Its Traffic', Economic Geography, vol. 24, no. 2, pp. 215-220.

Marshall, A. 1890. *Principles of Economics.* London: Macmillan.

Melo, P.C., D. J. Graham, D. Levinson, and S. Aarabi, 2012. 'Agglomeration, Accessibility, and Productivity: Evidence for Urbanized Areas in the US', paper submitted for the Transportation research Board 92nd Annual Meeting (2013).

Naess, P. & S. L. Sandberg, 1996. 'Workplace Location, Modal Split and Energy Use for Commuting Trips', Urban Studies, vol. 33, no. 3, pp. 557-580.

Newman, P. and J. Kenworthy, 1999. *Sustainability and Cities: Overcoming Automobile Dependence*, Washington D.C.: Island Press.

Ottaviano, G. I. P. and J.-F. Thisse, 2004. 'Agglomeration and Economic Geography,' in V. Hen- derson and J.-F. Thisse (eds.), *Handbook of Regional and Urban Economics,* Vol. 4. Amsterdam: North-Holland, pp. 2563–2608.

Overman, H. G. and D. Puga. 2010. 'Labour Pooling as a Source of Agglomeration: An Empirical Investigation,' in E. L. Glaeser (ed.), *Agglomeration Economics.* Chicago, IL: University of Chicago Press.

Parolin, B., 2005. 'Employment Centres and the Journey to Work in Sydney: 1981-2001', Second State of Australian Cities conference Griffith University, Brisbane, 30 Nov to 2 Dec, pp. 1-15.

Prud'homme, R. and C.W. Lee, 1999. 'Size, Sprawl, Speed and the Efficiency of Cities', *Urban Studies* 36: 1849-1858.

Rosenthal, S. S. and W. Strange, 2004. 'Evidence on the Nature and Sources of Agglomeration Economies,' in V. Henderson and Jacques-François Thisse (eds.), *Handbook of Regional and Urban Economics,* Vol. 4. Amsterdam: North-Holland, pp. 2119–2171.

Shen, Q., 2000. 'Spatial and Social Dimensions of Commuting', Journal of the American Planning Association, vol. 66, no. 1, pp. 68-82.

Shrank, D., B. Eisele, and T. Lomax, 2012. *TTI's 2012 Urban Mobility Report* ,Texas A&M Transportation Institute, December, online at: http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-report-2012.pdf.

Smith, A. 1776. *An Inquiry into the Nature and Causes of the Wealth of Nations.* London: Printed for W. Strahan, and T. Cadell.

Stigler, G. J., 1951. 'The Division of Labor is Limited by the Extent of the Market,' *Journal of Political Economy,* 59(3), 185–193.

Sveikauskas, L., 1975. 'Productivity of Cities,' *Quarterly Journal of Economics,* 89(3), 393–413. Syverson, C. 2004. "Market Structure and Productivity: A Concrete Example," *Journal of Political Economy,* 112(6), 1181–1222.

U. S. Bureau of Economic Analysis (BEA), 2013. *News Release: GDP by Metropolitan Area, Advance 2012, and Revised 2001–2011*, BEA 13-42. Online at http://www.bea.gov/newsreleases/regional/gdp_metro/gdp_metro_newsrelease.htm, Table 1. Current-Dollar Gross Domestic Product (GDP) by Metropolitan Area.

U.S. Census, 2000. Census Transportation Planning Package (CTPP) *Part 1 - Place of Residence*, and *Part 2 - Place of Work.*

U.S. Census, 2011. *Geographical Mobility 2008 to 2009*, P20-565, November, online at http://www.census.gov/prod/2011pubs/p20-565.pdf.

Veneri, P., 2010. 'Urban Polycentricity and the Costs of Commuting: Evidence from Italian Metropolitan Areas', Growth and Change, vol. 41, no. 3, pp. 403–429.

World Bank, 2014. *World Data Bank*, online at http://databank.worldbank.org/data/views/reports/tableview.aspx.

Yue, W, Y. Liu, Y and P. Fan, 2010. 'Polycentric Urban Development: the Case of Hangzhou', *Environment and Planning A*, vol. 42, pp. 563-577.

Zhao, P., B. Lu and G. Roo, 2011. 'The Impact of Urban Growth on Commuting Patterns in a Restructuring City: Evidence from Beijing', *Papers in Regional Science*, vol. 90, no. 4, pp. 735-754.

Zipf, G. K., 1949. *Human Behavior and the Principle of Least Effort,* Cambridge MA: Addison- Wesley.