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The Decline in Transit-Sustaining Densities in U.S. Cities, 1910 -2000

Shlomo Angel, Alex Blei, Jason Parent, and **Daniel A. Civco**

PRESENTING PAPER

The Decline in Transit-Sustaining Densities in U.S. Cities, 1910-2000

Shlomo Angel, Alejandro Blei, Jason Parent and Daniel A. Civco

Introduction: Urban Density and Sustainable Public Transit

People who live at higher densities use public transit more often than people who live at lower densities. Modern investigation into this density–transit relationship stretches back at least 30 years (Zupan and Pushkarev, 1977). While research recognizes this positive relationship, identifying a density level at which transit service becomes feasible has proven to be quite elusive. This obscurity rests on the complexity of the transit-density relationship and includes such disparate variables as transit accessibility, transit type, quality of service and consumer satisfaction, network design, public attitudes towards transit use, the pricing of fares, and subsidy levels.

Indeed, transit service is *possible* at any density level. A strong government commitment can subsidize near empty vans and buses in low density areas. Many places in the United States operate such services out of social equity and personal mobility concerns. But there is also poor public appetite for inefficient government spending. Strictly speaking, transit's vibrancy depends on healthy ridership and low density areas provide neither the ridership nor the preconditions for frequent and attractive bus service.

As we shall show, a century of density decline in US metropolitan areas has posed structural challenges to the provision of transit service. Surely, density decline cannot continue in perpetuity and the *rate* of density decline has clearly slowed down over the last 20 years. That said, population densities are now too low for transit to succeed as a *metropolitan* mobility strategy. While central business districts, suburban business districts, edge cities, transit-oriented neighborhoods and corridors within metropolitan regions may have experienced densification – and can be further densified in the future – these contributions are generally too small to constitute meaningful VMT or greenhouse gases reductions at the metropolitan level. As we shall show, both the share of the metropolitan populations that can sustain transit and the share of metropolitan areas that can sustain transit have declined substantially over time and are now exceedingly low in most U.S. metropolitan areas.

The renewed interest in the transit-density relationship is motivated by robust urban growth projections and by the accompanying challenges to urban mobility in light of the need for greenhouse gas reduction. Where and how the projected 100 new million Americans settle by 2050 (Kotkin, 2010), for example, will have important implications for the options available for moving people and goods. If limiting greenhouse gas emissions is to play an important role in the ways we approach planning and policy for the future city, then transportation, which contributes nearly a third of the nation's greenhouse gas emissions, and housing, which contributes 17 percent to total greenhouse gas emissions, must figure prominently. Within the transportation sector alone, passenger vehicles and public transit contribute 61 percent and percent respectively, to total emissions (US Department of Energy, 2008) .

Empirical studies have sought to peg transit's potential to threshold population densities, or "transit sustaining" densities. Admittedly, the notion of population density as a

common denominator for transit use does not tell the whole story, but there are compelling theoretical reasons for why it is a meaningful proxy. At a basic level, higher densities require sharing of resources over a transportation network. More people attempting to use the same amount of road, for example, would lead to congestion if users traveled by automobile. Transit vehicles, on the other hand, can package travelers more efficiently and increase throughput over a network. Transit operators benefit from high densities as this enables them to deliver mobility efficiencies with transit vehicles. The higher density, the more important alternatives for moving people rapidly and efficiently become. Moreover, the transit-density relationship can exhibit a virtuous cycle: clustering of population makes transit a more attractive alternative, which provides a customer base for transit, which provides revenues to operate more service, which attracts more people to use and live closer to transit, etc…

What, then, is a desirable density for transit service? We concur with Newman and Kenworthy (1989) and Holzclaw (1994) that a density of approximately 30 persons per hectare is a good rule of thumb for bus service. We further recognize that approximately 45 persons per hectare would allow for frequent and attractive bus service. The transit densities we have described apply to urban bus service, and are to be distinguished from densities for light rail and heavy rail transit.

In this paper, we explore transit sustaining density across time and space. First, we examine how cities' average densities, measured at the census tract level, have changed over a ninety year period ending in 2000; second, we assess the change in cities' transit sustaining areas, measured as a share of cities' total urbanized areas, over the same period; and third, we determine how cities' transit sustaining populations, measured as a share of total population, have changed over time.

II Historical Urban Tract Data for 20 U.S. Cities, 1910-2000

Historical population density data at the census tract level for U.S. cities and metropolitan areas are now readily available in digital maps (shapefiles) that can be analyzed using ArcGIS software. 20 U.S. cities were chosen for analysis for one principal reason: the availability of census tract digital maps (shapefiles) and population data extending as far back as possible, for some almost a full century. For seven of these cities—Baltimore, Boston, Chicago, Cleveland, New York, Pittsburgh, and St. Louis—tract density maps are available from 1910 onwards. Because of data loss, only three cities—Chicago, Cleveland, and Milwaukee—have tract density maps for 1920. For eleven additional cities—Buffalo, Cincinnati, Columbus, Detroit, Indianapolis, Los Angeles, Milwaukee, Nashville, St. Paul, Syracuse, and Washington—tract density maps are available from 1930 onwards, and for two of additional cities—Minneapolis and Philadelphia—tract density maps are available from 1940 onwards.

We chose to focus on this data set for three reasons. First, it was the only readily available ArcGIS-compatible data set that included information on historical urban densities at the tract level, going back to 1910. That meant that we could study the change in average density over a long period. The decennial census of 1910 was the first to utilize the concept of the census tract, or a small geographic area, that could be studied over time. Second, the availability of historical data on tract densities made it possible to

study change over time of several density metrics over and above average tract density, and to determine the extent to which the change over time in various tract density metrics paralleled the change over time in average tract density. The density metrics to be compared to average tract density were the share of the urban area with densities high enough to sustain public transport, and the share of the population inhabiting these areas. Third, the availability of density data for several decades made it possible to investigate both the average rate of density change over time and the second-order changes in that rate of change. Namely, it made it possible to investigate whether the rate of density change—whether positive or negative—was accelerating or slowing down over time. This in important because if we are interested in projecting urban densities into the future, we should not simply assume that densities will remain the same, nor that they will decline or increase at a constant rate.

The outer boundaries of the Urbanized Areas (UAs) in 2000 were taken to be the outer boundaries of the cities studied. The U.S. Census defines an Urbanized Area as a set of contiguous census block groups or census tracts with a minimum density of 1,000 persons per square mile that together encompass a population of at least 50,000 people. The Urbanized Areas in the 2000 U.S. Census were used to delimit the twenty metropolitan areas used in this part of the study. Census tract shapefiles for 2000 were downloaded from the Environmental Systems Research Institute (ESRI). (http://arcdata.esri.com/data/tiger2000/tiger_download.cfm) Historical census tract shapefiles and historical population data for these census tracts were downloaded from the National Historic Geographic Information System (http://www.nhgis.org/).

In the U.S. cities studied, we defined the urban land area of the metropolis as *the collection of 'urban' census tracts* within the set of administrative districts circumscribing the metropolitan area. In general, we use the term census tract loosely to mean a small geographical district within the administrative area of the city for which population data is available. The U.S. Census Bureau, for example, defines a census tract as follows:

> Census tracts are small, relatively permanent statistical subdivisions of a county…. Census tracts generally have between 1,500 and 8,000 people, with an optimum size of 4,000 people…. The spatial size of census tracts varies widely depending on the density of settlement. Census tract boundaries are delineated with the intention of being maintained over many decades…. However, physical changes in street patterns caused by highway construction, new developments, and so forth, may require occasional boundary revisions. In addition, census tracts occasionally are split due to population growth or combined as a result of substantial population decline. (U.S. Census, 2000)

Census tracts were defined as 'urban' when their densities exceeded a certain threshold. We used the U.S. Census threshold of 1,000 persons per square mile (3.86 persons per hectare) to include or exclude a tract from the urban area. The area thus defined by the U.S. Census is the area used by El Nasser and Overberg (2001), for example, in their measurement of U.S. sprawl. *Average Urban Tract Density* was thus calculated as the ratio of the total population in 'urban' tracts divided by their total area.

III The Three Density Metrics Used in This Study

In measuring density in the cities studied, we used three metrics: (1) the average 'urban' tract density; (2) the transit-sustaining area; and (3) the transit sustaining population.

The ***Average Density*** was defined as the ratio of the total population residing in 'urban' tracts in the metropolitan area and the total area of these tracts.

The ***Transit-Sustaining Area*** was defined as the share of the total 'urban' area of the metropolis in census blocks that had a density greater than 30 persons per hectare.

The ***Transit-Sustaining Population*** was defined as the share of the population in the urban area of the metropolis living in the Transit-Sustaining Area.

These three metrics were found to be correlated. In general, the higher the average density in a city, the higher its transit-sustaining area and its transit sustaining population. The correlation matrix among these three metrics is shown in table 1 below.

Metric	Average Density	Transit-Sustaining Area	Transit-Sustaining Population
Average Density	1.000		
Transit-Sustaining Area	0.903	1.000	
Transit-Sustaining Population	0.781	0.863	1.000

Table 1: Correlations among the Three Density Metrics Used in the Study
Note: The significance (2-sided) of all correlations was less than 0.001.

The high correlations among the three density metrics suggest that when the average density of a city declines, the transit-sustaining area and the transit-sustaining population are likely to decline as well. This is important because we may often have access to average density data, but not to the other two density metrics; and because average density data can be obtained for large administrative areas, while the other two metrics require finer-grain data.

IV The Decline in Average Density, 1910-2000

The decline in Average Density in the 20 U.S. cities studied is shown in figures 1-3. Figure 1 shows the average tract density in each city in every decade.

[Figure to be supplied later]

Figure 1: The Decline in Average Density in 20 U.S. Cities, 1910-2000

In ten of the twenty cities studied, maximum average tract densities are observed during the first year for which data is available. The year of observed maximum average tract density and the first year for which data is available, in parentheses, are as follows: 1910 – Baltimore (1910); 1920 – Milwaukee (1920); 1930 – New York (1910), Boston (1910), Chicago (1910), Pittsburgh (1910), St. Louis (1910), Cleveland (1910), Detroit (1930), Buffalo (1930), Columbus (1930), Syracuse (1930), Cincinnati (1930), and Indianapolis (1930); 1940 – Philadelphia (1940), Minneapolis (1940), and Nashville (1930), 1950 – Washington (1930) and St. Paul (1930); and 2000 – Los Angeles (1930).

With the exception of Los Angeles, 1950 marks a turning point; it is the year at which average tract density is declining for all cities. Average tract density decline began before 1950 for 17 of the 20 cities studied. Unlike any city in the sample, Los Angles shows density increases every decade over the period 1940-2000. With an average tract density of 29.2 in the year 2000, Los Angeles was the most densely populated urban area in our sample for the most recent data point, minimally higher than New York's 2000 average tract density of 26.4. In 2000, average tract density for individual cities ranges from 8.7 to 29.2 persons per hectare.

Figure 2 shows the decline in the average tract density of all 20 cities studied. Our calculation shows that average tract density has declined every decade, from 70 persons per hectare in 1910 to 14.6 persons per hectare 2000. As our sample does not include data for every city for every date, reported averages reflect the availability of data. A negative exponential curve fitted to the data shows a high degree of fit ($R^2 = 0.97$). It suggests that average tract densities declined at the long-term rate of 1.9 percent per annum during the period studied. The convergence of the upper and lower error range at the 0.05 significance level mirrors the increase in the number of observations for later periods, and indicates that the sample has become more uniform over time. In other words, cities' average tract densities were more similar to each other in 2000 than they were in the past.

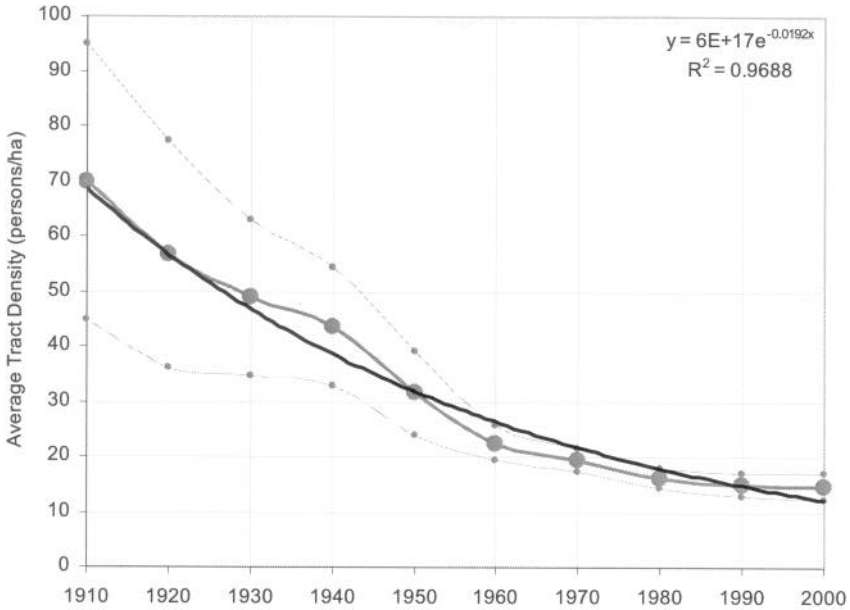

Figure 2: The Average Decline in Average Density in 20 U.S. Cities, 1910-2000
Note: Thin lines show upper and lower error range at 0.05 level of significance (2-tailed)

Figure 3 shows the annual rate of change in average density in every decade. Average density was stable between 1910 and 1930. It began to decline rapidly after 1930 at accelerated rates, reaching a rate of 3 percent per annum in the 1940s and 1950s. It then began to slow down, reaching an annual rate of less than 0.5 percent in the 1990s. This confirms that average population density in U.S. urban areas has reached a plateau at very low density levels and is unlikely to decline further in the years to come. Unfortunately, as we shall see below, densities at this plateau are too low to sustain public transit.

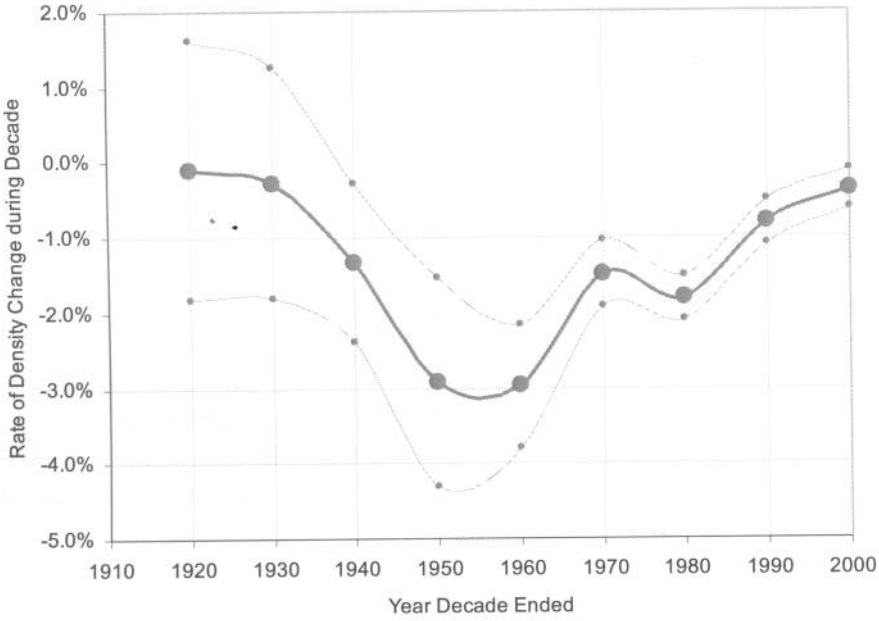

Figure 3: Annual Rate of Change in Average Density, 1910-2000
Note: Thin lines show upper and lower error range at 0.05 level of significance (2-tailed)

V The Decline in Transit-Sustaining Area, 1910-2000

The decline in Transit-Sustaining Area in the 20 U.S. cities studied is shown in figures 4-6. This metric relates the area of census tracts with population densities over 30 persons per hectare as a share of total urban area. Figure 4 shows the transit-sustaining area in each city in every decade.

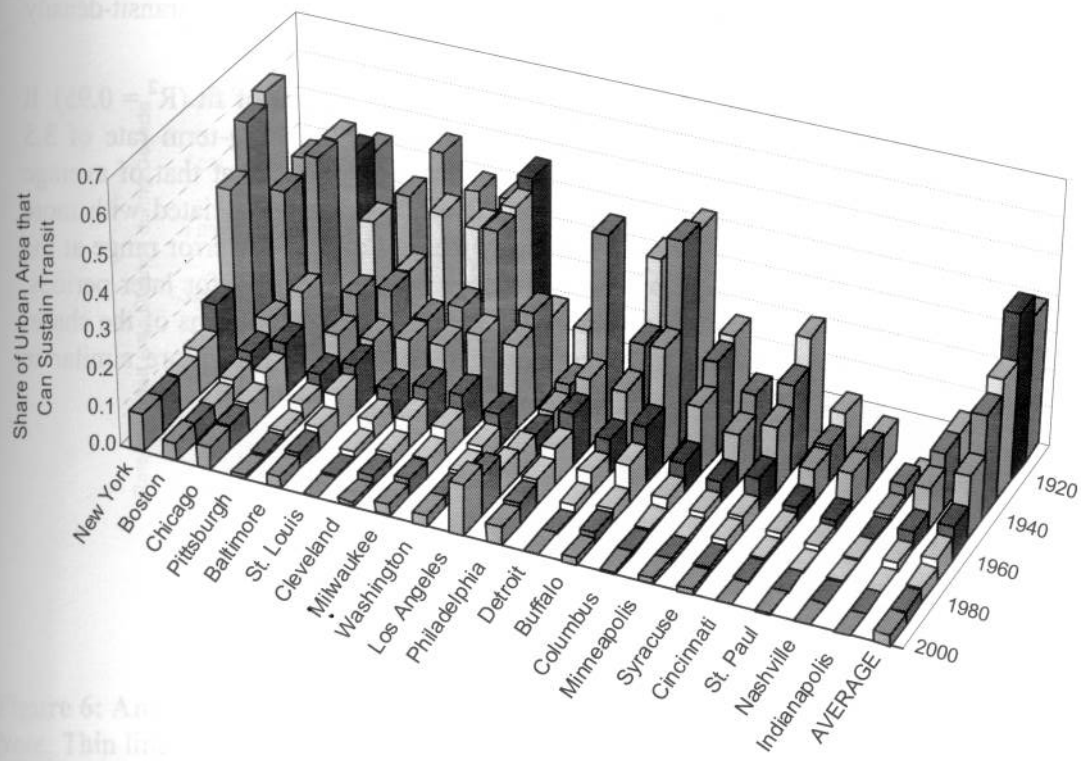

Figure 4: The Decline in Transit-Sustaining Area in 20 U.S. Cities, 1910-2000

Maximum transit sustaining areas for individual cities are observed at the following years at the following rates: 1920 – Milwaukee (0.51); 1930 – New York (0.63), Chicago (0.54), Pittsburgh (0.34), St. Louis (0.41), Cleveland (0.39), Los Angeles (0.19), Detroit (0.43), Columbus (0.27), Syracuse (0.31), Cincinnati (0.13), Indianapolis (0.15); 1940 – Boston (0.43), Washington (0.26), Philadelphia (0.51), Buffalo (0.54), Minneapolis (0.18), Nashville (0.04); and 1950 – St. Paul (0.10).

With five exceptions (New York, Boston, Los Angeles, Minneapolis, St. Paul) transit sustaining area continually decreased every decade after reaching its maximum. New York, Boston, Minneapolis and St. Paul experienced minor increases from 1990 to 2000. After reaching its peak in 1930, the transit sustaining area of Los Angeles declined until 1960 but has been increasing until 2000. With a transit sustaining area equal to 0.14 of its total area, Los Angeles has the highest observed transit sustaining area in 2000. New York is the second highest observation, with a transit sustaining area equal to 0.10 of its total area. In 2000, the transit sustaining area of individual cities ranges from 0.00 to 0.14 of total urban area.

Figure 5 shows the decline in the average transit-sustaining area of all 20 cities studied. The average share of U.S. urban areas that was dense enough to sustain public transport increased between 1910 and 1920 before it began its continuous decline. The authors recognize fault with the assumption that a transit sustaining density of 30 persons per hectare can be accurately applied for a duration of 90 years. Changes to transit's cost structure as well as the economic and technological realities commuters faced are duly noted. Even if transit sustaining densities are different now than they were in the past,

however, we find value in the ability to compare what we know about transit-density relationship today with density levels in the past.

A negative exponential curve fitted to the data shows a high degree of fit ($R^2 = 0.95$). It suggests that the average transit-sustaining area declined at the long-term rate of 3.5 percent per annum during the period studied, a more rapid decline that that of average density. This finding suggests that a doubling of population was associated with more than a doubling of "urban" land. The convergence of upper and lower error range at the 0.05 significance level is due to the increased number of observations for later periods, and indicates that the sample has become more uniform over time in terms of the shares of transit-sustaining areas in cities. In other words, these shares were more similar in 2000 than they were in the past.

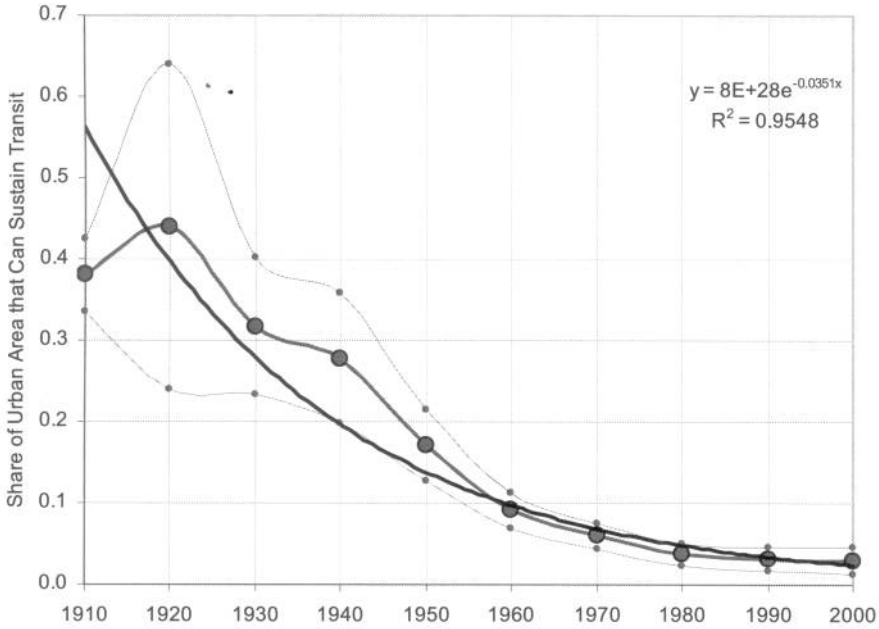

Figure 5: The Average Decline in the Transit-Sustaining Area in 20 U.S. Cities, 1910-2000

Note: Thin lines show upper and lower error range at 0.05 level of significance (2-tailed)

Figure 6 shows the annual rate of change in transit-sustaining area in every decade. The rate was stable at almost 0 percent between 1910 and 1930. It began to decline rapidly after 1930 at accelerated rates, reaching a rate of 7 percent per annum in the 1960s and 1970s. It then began to slow down, reaching an annual rate of less than 3 percent in the 1990s. Transit sustaining area in the United States was still declining in 2000, but less rapidly than before. This clearly poses a challenge: increased transit use to levels that can begin to affect greenhouse gas emissions requires, at the very least, halting this decline.

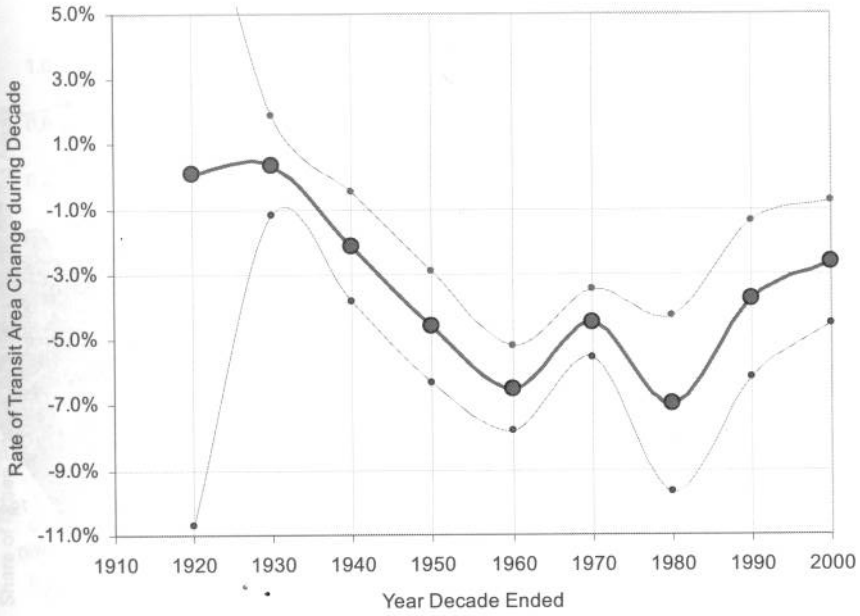

Figure 6: Annual Rate of Change in Sustainable Transit Area, 1910-2000
Note: Thin lines show upper and lower error range at 0.05 level of significance (2-tailed)

VI The Decline in the Transit-Sustaining Population, 1910-2000

The decline in Transit-Sustaining Population in the 20 U.S. cities studied is shown in figures 7-9. Figure 7 shows the transit-sustaining population in each city in every decade. This metric relates the urban population living at transit sustaining densities as a share of total urban population. The reader should note that this metric is quite different than the transit-sustaining area discussed in the previous section. In theory, as well as in practice, it is possible for the share of the transit-sustaining area to be quite small and for the share of the transit-sustaining population to be quite large. Indeed, it may be argued that the latter metric is more appropriate for discussing the effect of transit use on greenhouse gas emissions and energy savings.

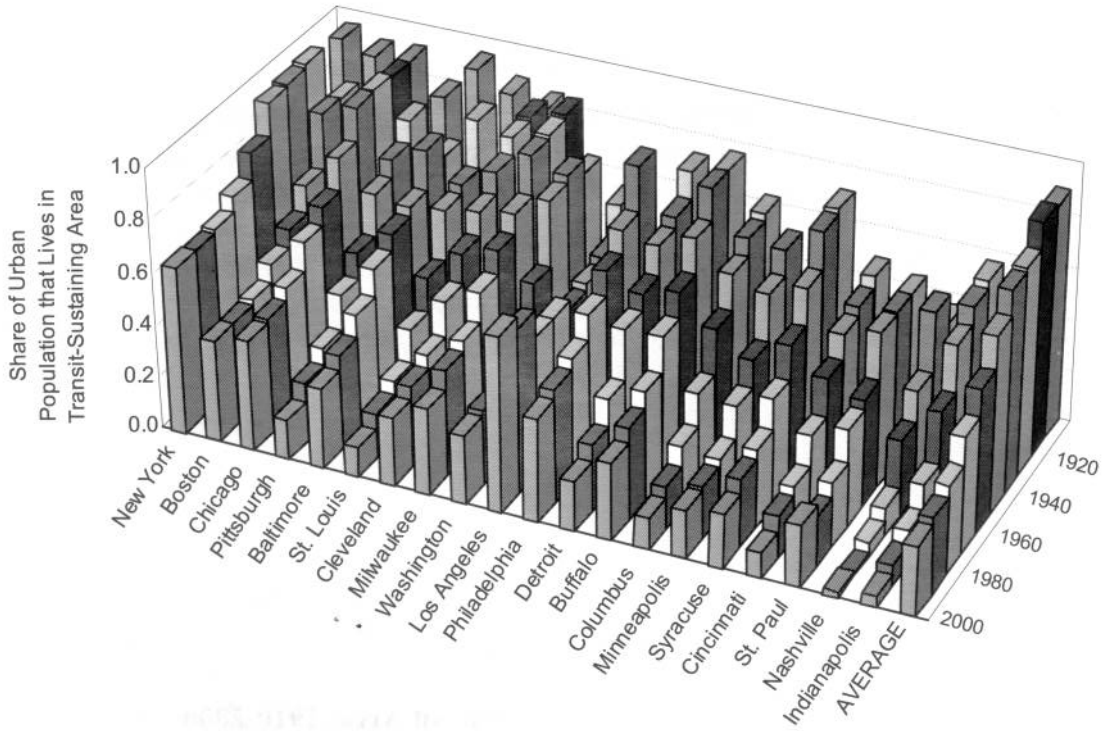

Figure 7: The Decline in Transit-Sustaining Population in 20 U.S. Cities, 1910-2000

Maximum transit sustaining populations for individual cities are observed at the following years at the following rates: 1910 – Baltimore (0.94), Boston (0.91); 1920 – Cleveland (0.87), Milwaukee (0.91); 1930 – New York (0.97), Chicago (0.92), Pittsburgh (0.84), St. Louis (0.90), Los Angeles (0.69), Detroit (0.88), Columbus (0.78), Syracuse (0.86), Cincinnati (0.64), Indianapolis (0.71); 1940 – Washington (0.84), Philadelphia (0.94), Buffalo (0.92), Minneapolis (0.74), St. Paul (0.60), and Nashville (0.64). In the year 2000, Los Angeles had the highest transit sustaining population as a share of total population (0.68) edging out the nation's most famous transit city, New York (0.65).

Figure 8 shows the decline in the average transit-sustaining population of all 20 cities studied. The average share of U.S. urban population that sustained public transport increased between 1910 and 1920 before it began it continuous decline. The percent of the population living at transit sustaining densities was historically very high. In 1910, 89 percent of cities' populations lived at densities that could support modern day transit. In 1930, this number increased for some cities and decreased for others, ultimately resulting in a net decrease. Eighty percent of cities' populations were transit sustaining in 1930; in New York, this figure hovered around 97 percent.

A negative exponential curve fitted to the data shows a high degree of fit ($R^2 = 0.95$). It suggests that the transit-sustaining population declined at the long-term rate of 1.5 percent per annum during the period studied, a slower decline than that of average density. This suggests that new urban development at the metropolitan periphery may have been at densities that were too low to sustain public transit. This may have led to a rapid increase in the share of the urban area that cannot sustain transit. Still, it may have contained too small a share of the total metropolitan population to affect the share of the urban population living in areas with high enough densities to sustain transit.

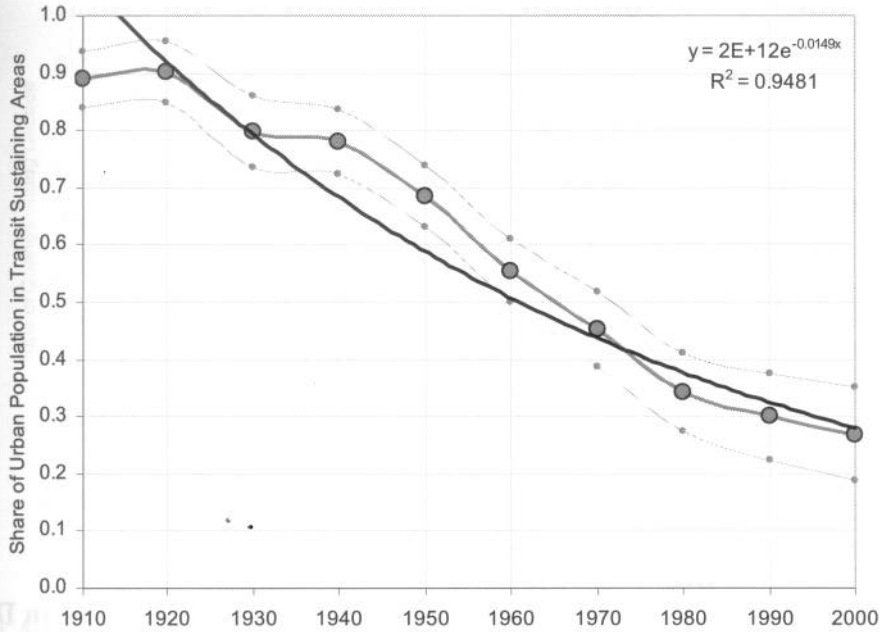

Figure 8: The Average Decline in the Transit-Sustaining Population in 20 U.S. Cities, 1910-2000

Note: Thin lines show upper and lower error range at 0.05 level of significance (2-tailed)

Figure 9 shows the annual rate of change in transit-sustaining population in every decade. The rate was stable at almost 0 percent between 1910 and 1930. It began to decline rapidly after 1940 at accelerated rates, reaching a rate of almost 3.5 percent per annum in the 1970s. It then began to slow down, reaching an annual rate 1.5 percent in the 1990s. In other words, the transit-sustaining area in U.S. cities has always declined, but at slower rates over the last 20 years.

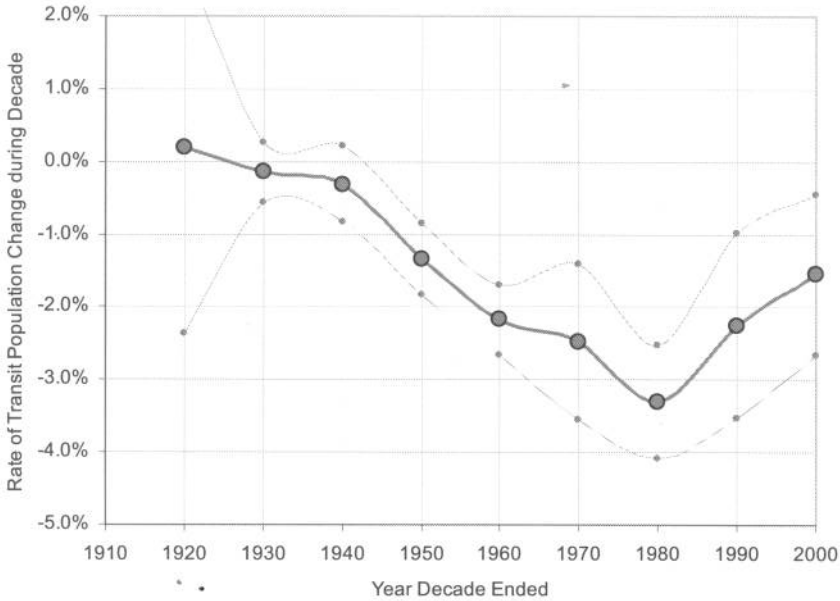

Figure 9: Annual Rate of Change in the Sustainable Transit Population in Different Decades, 1910-2000
Note: Thin lines show upper and lower error range at 0.05 level of significance (2-tailed)

In conclusion, we compared the annual rates of decline of the three metrics in one graph. Figure 10. Beginning in 1980, we observe an easing of the rate of decline. This comparison is instructive. It shows that the general pattern is similar in all three curves. All three increased their rate of decline in 1930 and decreased it from 1980 onwards. The three reached their lowest rates of decline in different periods. Average densities had their lowest rates of decline earlier, in the 1950s, while the other two reached their most rapid rates of decline later, possibly in 1980.

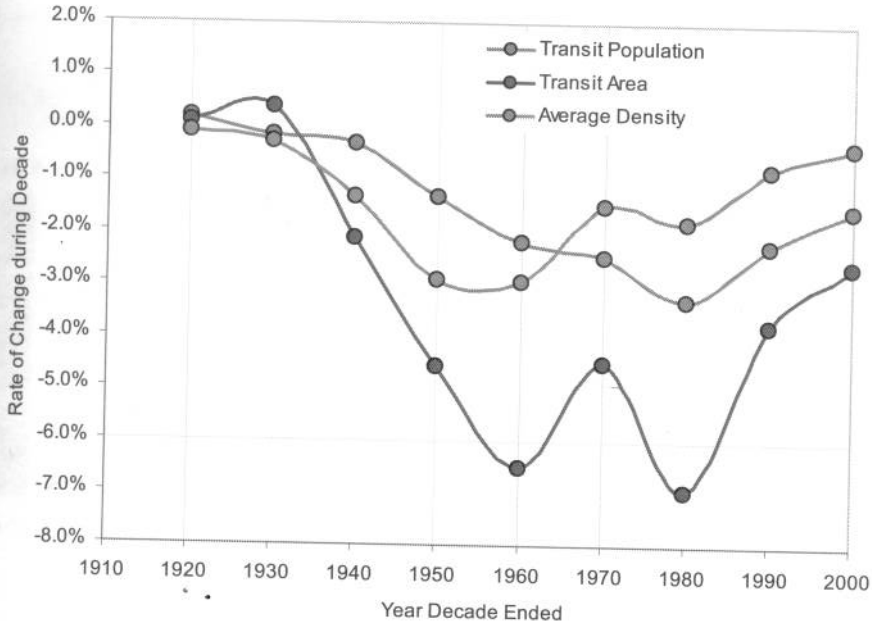

Figure 10: A Comparison of the Annual Rates of the Three Metrics, 1910-2000

VII Transit-Sustainable Densities in U.S. Metropolitan Areas in 2000

Figures 11-13 broaden the investigation of transit sustaining population and transit sustaining area to all census defined urbanized areas in the year 2000. Population and land area for urbanized areas were then examined in aggregate to determine the percent of total U.S. urban population and U.S. urban land that was transit sustaining.

Figure 11 shows the distribution of U.S. urbanized areas by their transit sustaining populations. Our analysis is based on 447 of 453 urbanized areas in the year 2000. Data loss resulted in the omission of six urbanized areas from this analysis: Anchorage, AK; Cumberland MD-WV-PA; Fairbanks, AK; Hanford, CA; Honolulu, HI; and Kailua-Kaneohe, HI.

Nearly 47 percent of all urbanized areas had 0 percent transit sustaining populations, 67 percent of all urbanized areas had less than 10 percent transit sustaining populations, 13 percent of urbanized areas had over 20 percent transit sustaining populations, and 2 percent of urbanized areas had greater than 50 percent transit sustaining populations.

The top five urbanized areas for transit sustaining populations are: San Francisco-Oakland, CA – 71.4 percent; Los Angeles-Long Beach-Santa Ana, CA – 67.7 percent; State College, PA – 65.3 percent, New York-Newark, NY-NJ – 64.7 percent; and San Jose, CA – 54.7 percent.

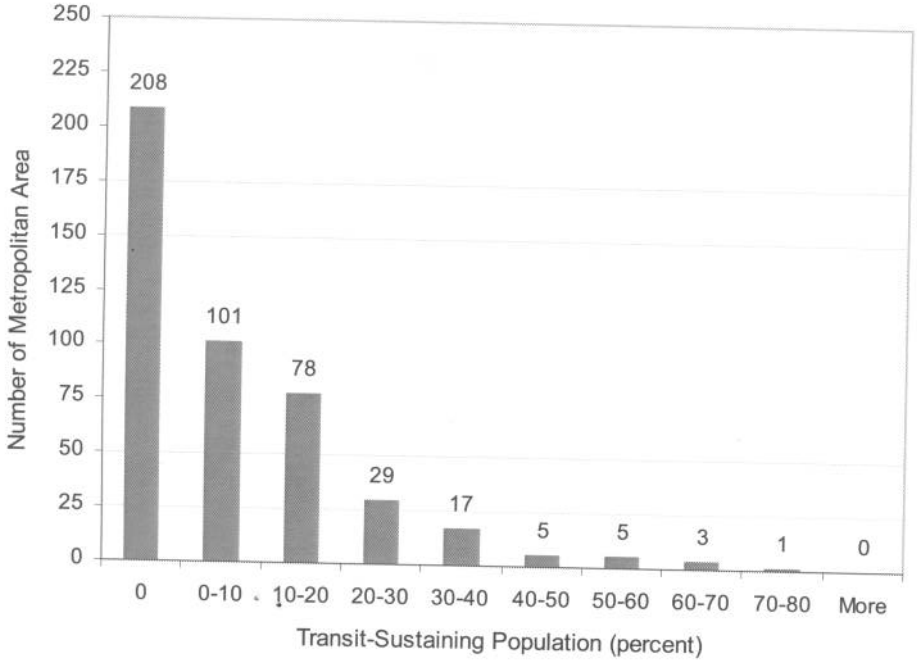

Figure 11. The Distribution of Urbanized Areas by their Transit Sustaining Populations

Figure 12 shows aggregate U.S. urban population by density range. Nearly 73 percent of the U.S. urban population lived at population densities below 30 persons/hectare. Nearly a quarter of U.S. urban population lived at a population density of less than 10 persons per hectare.

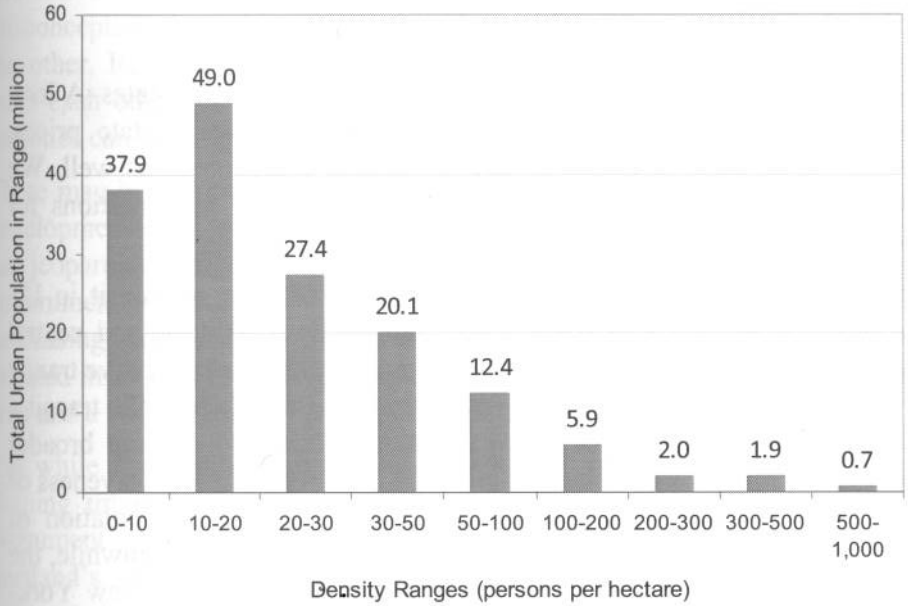

Figure 12. The Distribution of Total U.S. Urban Population by Density Range (persons per hectare), 2000

Figure 13 shows the amount of urban land (thousands of hectares) in the year 2000 that was associated with each density range. More than half of all urban land (52 percent) had population densities in the 0-10 persons per hectare range. Nearly 93 pecent of all urban land in the U.S. fell below 30 persons per hectare.

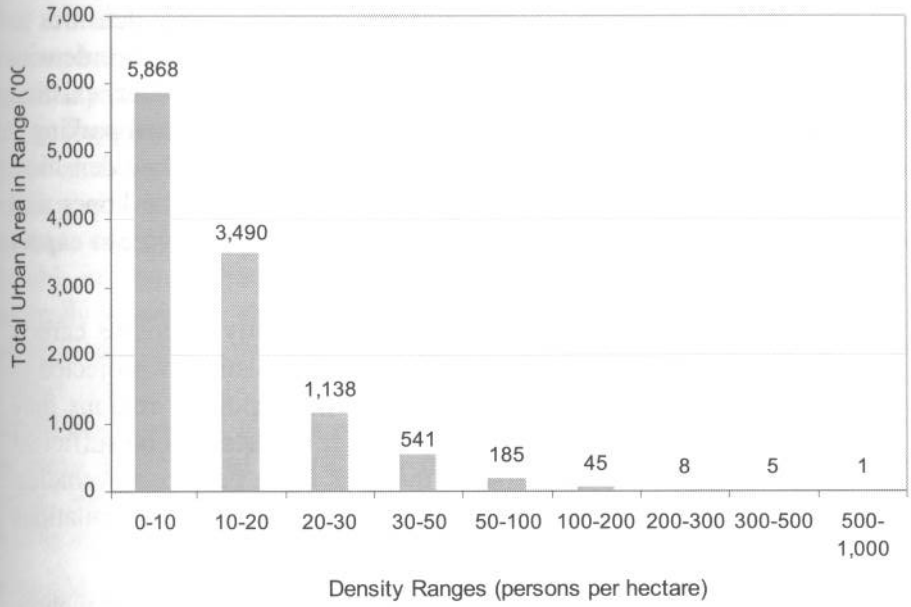

Figure 13. The Distribution of Urban Land (000's of hectares) by Population Density

VIII Conclusions and Policy Implications

Transit fulfills vitally important mobility needs of cities across the United States. A long list of positive externalities, including benefits to public health, real estate prices, personal safety, and lower household spending are associated with transit as well. We support and encourage densification within urban areas so that the preconditions for attractive and affordable transit may thrive.

We also recognize widespread structural challenges to the provision of transit in US metropolitan areas. While it is true that several neighborhoods, corridors, and central business districts retain population densities that can sustain frequent and attractive transit service, a majority of urban Americans live at densities that are too low to make transit a realistic mobility alternative. Current debates over transit's ability to achieve broader societal goals, such as combating climate change, must acknowledge the pervasiveness of density decline. In the year 2000, for instance, 27.3 percent of the population of urbanized areas in the United States lived at sustainable transit densities. Meanwhile, the transit sustaining area of cities is also, on average, declining. Interestingly, New York-Newark, the nation's most populous urbanized area, boasts the highest rate of transit use among commuters (51 percent) but is not the most transit sustaining in terms of metropolitan population density. That distinction belongs to the Los Angeles-Long Beach-Santa Ana urbanized area where only 11 percent of commuters use public transportation (Brookings, 2010). The overall transit picture is challenging, but examples like Los Angeles bode well for transit proponents; it would appear that the conditions exist to attract a portion of commuters to transit in a select few urbanized areas.

Research indicates that the likelihood that individuals adopt transit is linked to population density. Conventional wisdom suggests that policies and programs that raise densities to meet prescribed thresholds can be put into effect. A century of continuous density decline, however, makes this proposition much easier said than done. Moreover, existing policies and regulations at the local level such as minimum lot sizes, mandated parking – even the number of kitchens allowed in residential buildings – exacerbate low densities. The preponderance of low population density forces us to rethink what the hopes and goals for public transit should be, as well as the size and type of benefits we can expect transit to deliver.

If current thinking considers public transit as a way to significantly decrease carbon emissions, expectations should be based on the number of people realistically projected to adopt transit. To be sure, densification of some areas within metropolitan regions may lead to higher rates of transit use, but it is unlikely that density increases will be sufficient to address the scale of the problem posed by carbon emissions from passenger vehicles. Both the average densities of urbanized areas and the share of urbanized area populations that are transit sustaining are declining.

Efforts to increase population density would be a welcome development nevertheless, and particular consideration must be placed on the policy instruments available. Strategies aimed at the limiting the fragmented spatial structure of low density developments, such as leapfrog development, can be conflated with strategies designed to increase built up area density. Current discussions often lump fragmented development

and low density development together under the banner of sprawl, thus promoting the misconception that strategies designed to address one aspect of sprawl will also address the other. Research suggests that fragmentation and density can be quite independent from each other, however, and that the policy instruments for increasing built up area densities can be different from those that address fragmentation (Angel et al., 2010).

There may be compelling reasons for limiting fragmented urban development. Leapfrog development can lead to high public infrastructure costs and uncoordinated development can jeopardize scarce farmland, wetlands, or fragile ecological areas. *Metro,* the regional government entity for the Portland, Oregon metropolitan area, has had great success in decreasing fragmentation with its urban growth boundary. Since the boundary was instated in 1973, Portland has experienced a dramatic "filling in the gaps" of its built up area and a concurrent preservation of open space beyond the boundary.

Yet while Portland's growth boundary has proven to be effective as an instrument for shaping urban spatial structure, it has not, strictly speaking, proven effective as an instrument for increasing population density in its built-up areas. More to the point, Portland's growth boundary has successfully reduced fragmentation, making it more compact, but to the surprise of many, Portland's built up area density has declined. Possible explanations might include the relatively large size of new construction versus old construction and decreasing average household size.

Densification proponents might therefore favor a different set policies and regulations such as: removing restrictions on higher density development; allowing the subdivision of homes into two or more units, and renting of one or more units; incentives for building on small lots and disincentives for building on large ones, encouraging apartment house construction, and so on.

But the aim might be both an increase in built up area density and a decrease in fragmentation – as is likely the case for transit– and there may be a need to address these issues separately, each with its own set of policy instruments. High density development that is fragmented in its spatial structure will meet the density threshold in theory, but its spatial structure will also increase the distance between locations – thus increasing the walking distance to stations – increase travel times and vehicle miles traveled, and increase energy use and pollution. More compact (or less fragmented) spatial structure should, in theory, have the opposite effect on walking distance and travel times, and generally speaking, should strengthen transit's viability as a mobility alternative. The appropriate density metric for assessing transit's potential should therefore extend beyond a strict reading of population density of built-up area. The appropriate density metric should also account for the open spaces, or the level of fragmentation, surrounding built up areas. This type of metric may prove more useful in relating information about urban spatial structure that is favorable to transit. The *spatial structure of transit sustaining density* is an area that deserves further attention from researchers and policy makers.

It would be remiss to exclude the role fuel technology in a discussion about urban mobility and greenhouse gas. If the main argument for transit were environmental, one could argue that the real problem was one of finding less polluting fuel sources for passenger vehicles. Certainly, advances in fuel and automotive technology will be beneficial to the natural environment and should be pursued. However we also believe

that the combined benefits of transit extend well beyond a purely environmental focus, and this helps justify the pursuit of policies and regulations that are conducive to transit.

The sobering reality of density decline should not mean that transit is a lost cause. Transit provides billions of trips each year and delivers enormous economic and social benefits. Our intent, rather, is to offer new insights on transit's potential benefit based on our evaluation of population density. We want discussions about population growth, urban spatial structure, urban mobility, and greenhouse gas to accurately assess what we know about the relationship of transit and density. We hope to have offered new perspectives on metropolitan mobility and green house gas reduction. A full understanding of the problems and causes of the transit-density relationship will lead to more meaningful and lasting solutions.

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