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Street Grids and Economic Opportunity in Washington, DC

Recent work in economics has both identified a meaningful geographic variation in economic opportunity in the U.S. (Chetty et al. 2014), and established a causal link between the neighborhood a child grows up in and their likelihood of economic upward mobility (Chetty, Hendren, and Katz 2016). This zipcode inequality is laid bare in the Opportunity Atlas (https://www.opportunityatlas.org/), a public website that allows users to explore data on economic outcomes from the scale of the entire nation to the block where they grew up. To do so, the site draws on anonymized longitudinal administrative data for over 20 million people born between 1978-83 that tracks each individual's place of residence through the age of 27 and estimates their incomes at age 35 (Chetty et al. 2018). One particular metric that can be constructed from this data is *absolute mobility at the 25th percentile*, which looks at the expected income percentile rank achieved in adulthood by children born to parents in the bottom quarter of the national income distribution. This allows policymakers to measure one particular idea of the American dream, the ability to move out of poverty from one generation to the next, and sets a calculable benchmark that they can work towards improving.

In light of this growing body of evidence validating and quantifying the importance of place, what exactly it is about an area that provides for greater or lesser economic mobility has become the subject of ongoing, interdisciplinary study. Urban planning, as a field concerned with both the spatial and socioeconomic structures of our cities, is one of the disciplines I would like to see more involved in this joint endeavor. As an urban planner, I would like to propose one possible contribution our field might make by looking at one of the most foundational elements of urban environments — the street grid.

Street grid design is a defining characteristic of a place, one of the earliest decisions made about a neighborhood's form, and a fairly persistent trait that creates a "spatial lock-in" (Boeing 2021, 10) lasting for generations. While different street layouts have fallen in and out of fashion over the years, today's sustainability-minded, and often pro-density planners have come to favor more tightly-gridded networks once again for their association with lower vehicle-miles traveled (Ewing and Cervero 2010) and subsequent reductions in greenhouse gas emissions. Myriad other advantages of the resulting dense cities have also been extolled by planners and urban economists alike (Glaeser 2011).

In addition to these environmental and agglomeration benefits, I believe it is also worth exploring whether more connected and compact street grids might lead to greater economic opportunity and upward mobility for that neighborhood's residents. The underlying hypothesis here is not that the number of turns someone has to make on their way to work or the grocery store has itself a defining impact on their economic outcomes later in life, but rather that the design of the street network in a neighborhood sets the spatial conditions for certain types of development (Busquets 2019), mobility patterns (Cervero and Kockelman 1997), and social interactions[1] that may be more or less conducive to the economic prosperity of its residents.

[1] The link between social capital and spatial density is a somewhat debated one. Initially the idea that lower density areas led to lower social connectivity was put forth by Robert Putnam in his seminal book *Bowling Alone*, but it has been called into question more recently by studies like Brueckner and Largey's "Social Interaction and Urban Sprawl."

From an analytical perspective, street network connectivity and structure may also provide a useful, quantifiable stand-in for other hard-to-measure aspects of a neighborhood's character and design. Street network analysis is a well established practice in the fields of transportation planning and engineering, with many potentially informative tools that could be borrowed to conduct this kind of study. Some common measures of street grid character range from simple calculations of average block length (where longer blocks correlate with less connected, less gridded systems), to counting the number of roads that meet on average at an intersection, or *mean nodal degree* in network theory terms (where a cul-de-sac has a degree of 1, while a typical city-grid intersection has a degree of 4), to more complex formulas for determining a street network's entropy, orientation, and order (Boeing 2019). Further, researchers have also developed composite indices of urban sprawl (Ewing and Hamidi n.d.) and categorical classifications of neighborhood type (Ralph et al. 2016) at the census tract level, which extend their focus beyond the street grid into other place-based attributes.

Exploring the relationship between the measures of economic mobility provided in the Opportunity Atlas and all of these various metrics would prove to be a worthwhile investigation into the impact of spatial planning on socioeconomic outcomes. However, for this short assignment I will limit my exploratory analysis to studying the correlation between the mean nodal degree[2] of the street network in Washington, DC in 1999[3] and the previously described absolute mobility at the 25th percentile metric of economic mobility by census tract.

My hometown of Washington, DC presents a particularly interesting case study for testing this hypothesis because of its uniquely varied street plan. Across different neighborhoods, the structure ranges from a classic orthogonal grid, to a suburban-style curvilinear system, and even to a radial structure around its many circles (see Figure 1). Having grown up in two different neighborhoods in the city with very different street structures, I can attest first hand to the notably different character it creates in an area.

Example of an orthogonal street grid in A.U. Park

Example of a curvilinear street grid in Spring Valley

Example of a radial street grid in Dupont Circle

Figure 1. Aerial images of the different street grid layouts across neighborhoods in Washington, DC (Google Earth, 2023)

[2] For a more detailed view of the use and usefulness of mean nodal degree as a measure of street design and sprawl, see Barrington-Leigh and Millard-Ball's paper "A century of sprawl in the United States."

[3] The decision to analyze the street network from 1999 was made to most closely align with the period when the children whose outcomes are studied in the Opportunity Atlas would have been living there.

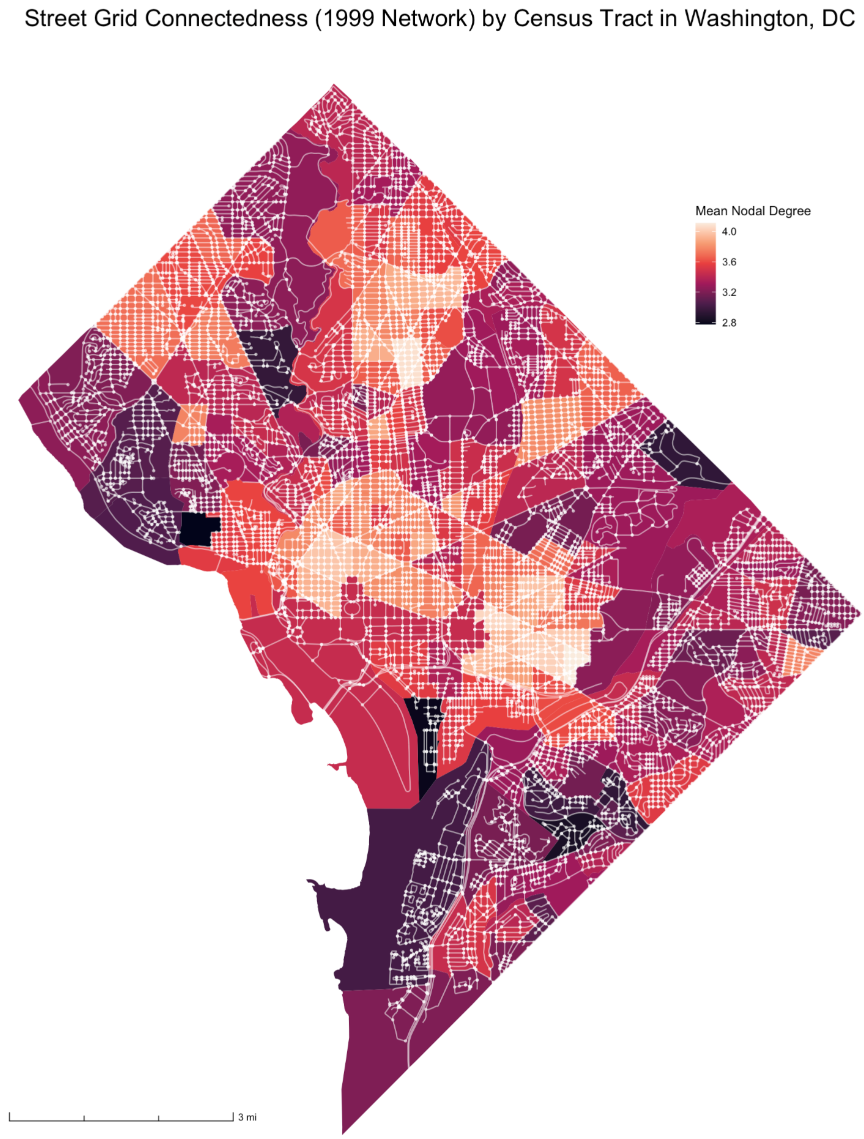

Figure 2. Map showing the mean nodal degree by census tract along with the street segments and nodes

The first step in conducting this analysis is to calculate the connectedness of the street grid, using the mean nodal degree metric, within each census tract. This involved taking street centerline data for the 1999 road network in Washington, DC (Open Data DC 2001), generating nodes at each intersection using GIS software, then conducting a spatial operation to count the number of street segments that touch each node using the *sf* package in R (Pebesma 2018). Plotting the results in a choropleth map (see Figure 2) helps visually confirm the spatial variation across the city, and that tracts with a more rectilinear grid score higher on this metric than ones with winding roads. To help interpret these potentially unintuitive numbers, a histogram of mean nodal degree has been provided below (see Figure 3) along with a graphic from Barrington-Leigh and Millard-Ball (2015) that places famous street systems through U.S. history on the same mean nodal degree scale for context (see Figure 4). The distribution of scores across the city can also be clarified by looking at some key summary statistics and comparing them to the references provided in Figure 4. Of the 179 tracts in Washington, DC, the minimum score is 2.78 (similar to the Loops and Lollipops) and the maximum is 4.10 (higher than the Gridiron), while both the median and mean score are 3.48 (closest to the New Urbanism model). The standard deviation of mean nodal degree across tracts is about 0.28, which offers little practical information about the variation in street griddedness without comparable deviations in other cities or counties (unavailable in this analysis).

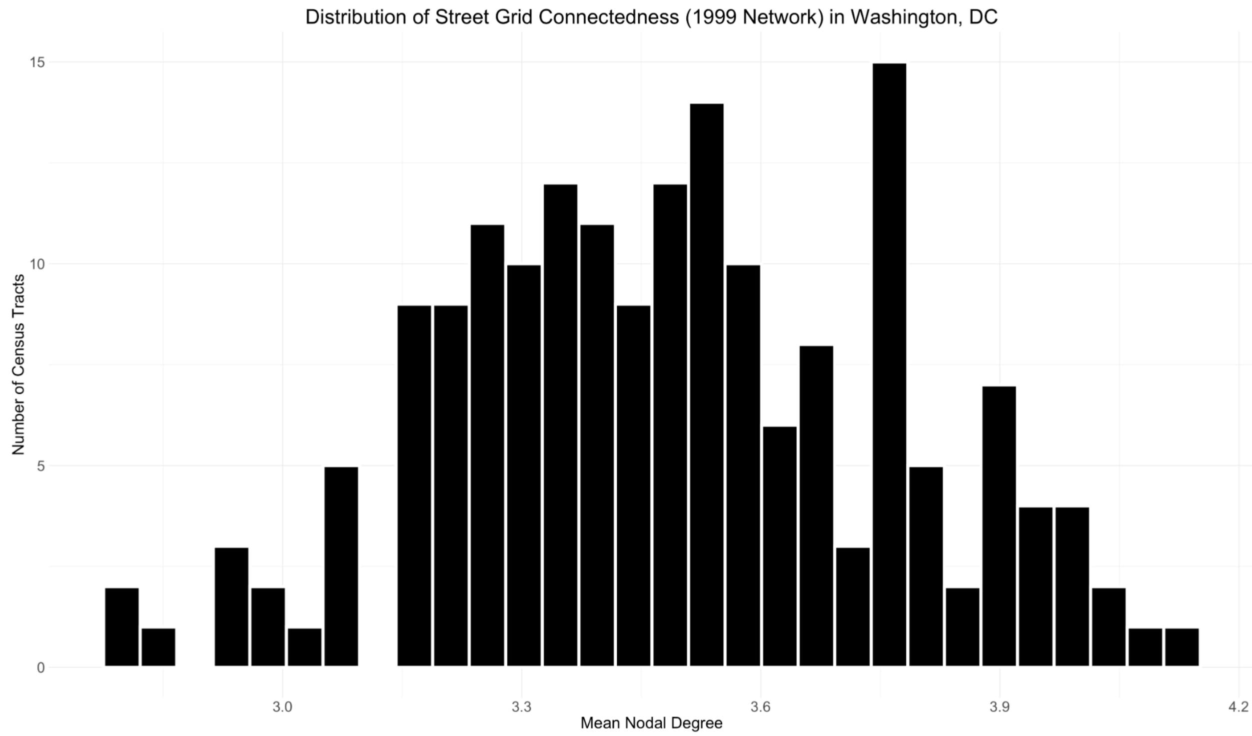

Figure 3. Distribution of mean nodal degree in Washington, DC census tracts

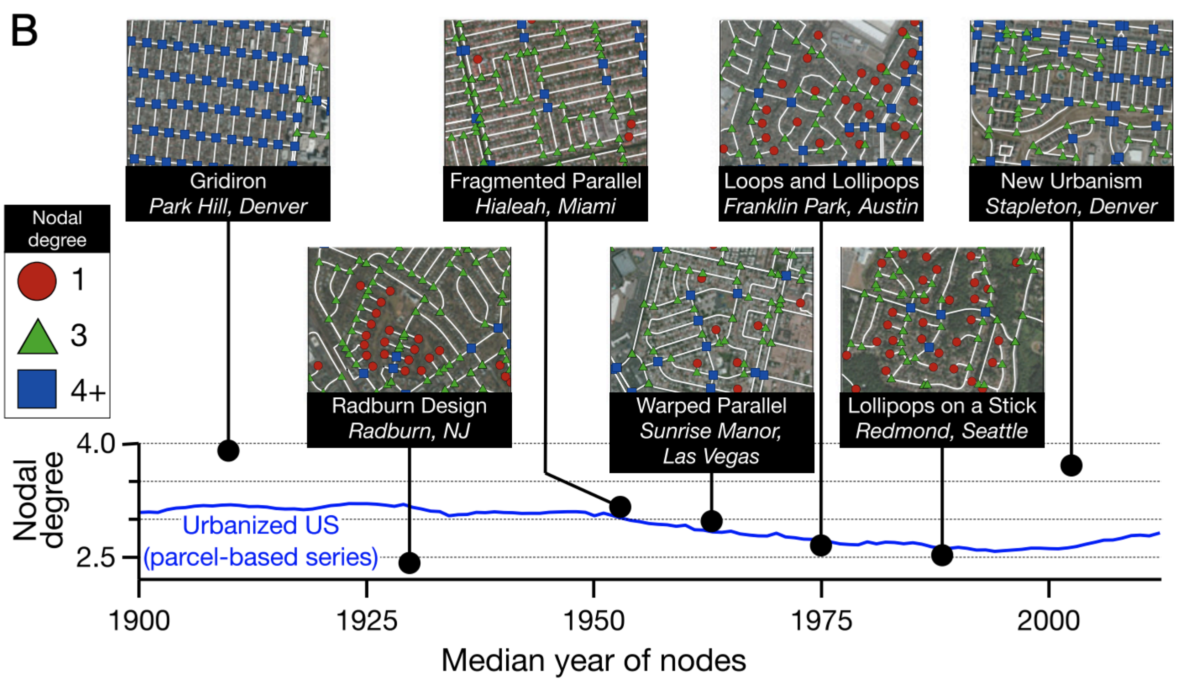

Figure 4. Chart illustrating the mean nodal degree of different notable street systems through U.S. history (Barrington-Leigh and Millard-Ball 2015, 8245)

With this understanding of the street network established, the relationship between street connectedness and economic outcomes can start to be explored. A scatterplot with a univariate regression line can help get an initial, but simplistic, picture of the correlation between these two measures (see Figure 5). This first test indicates a slight but statistically significant upward correlation, with an increase of 4.6 income percentiles for a one unit increase in mean nodal degree (roughly the difference between living in a Warped Parallel structure and a fully Gridiron system as shown in Figure 4). Confirming the statistical significance of this association, the p-value from this model is 0.0098 which indicates a remarkably low probability that this finding is due to random chance, and the adjusted r^2 value is 0.032 suggesting that about 3.2% of the total variation in the expected income percentile rank can be attributed to the mean nodal degree of the street grid in that tract.

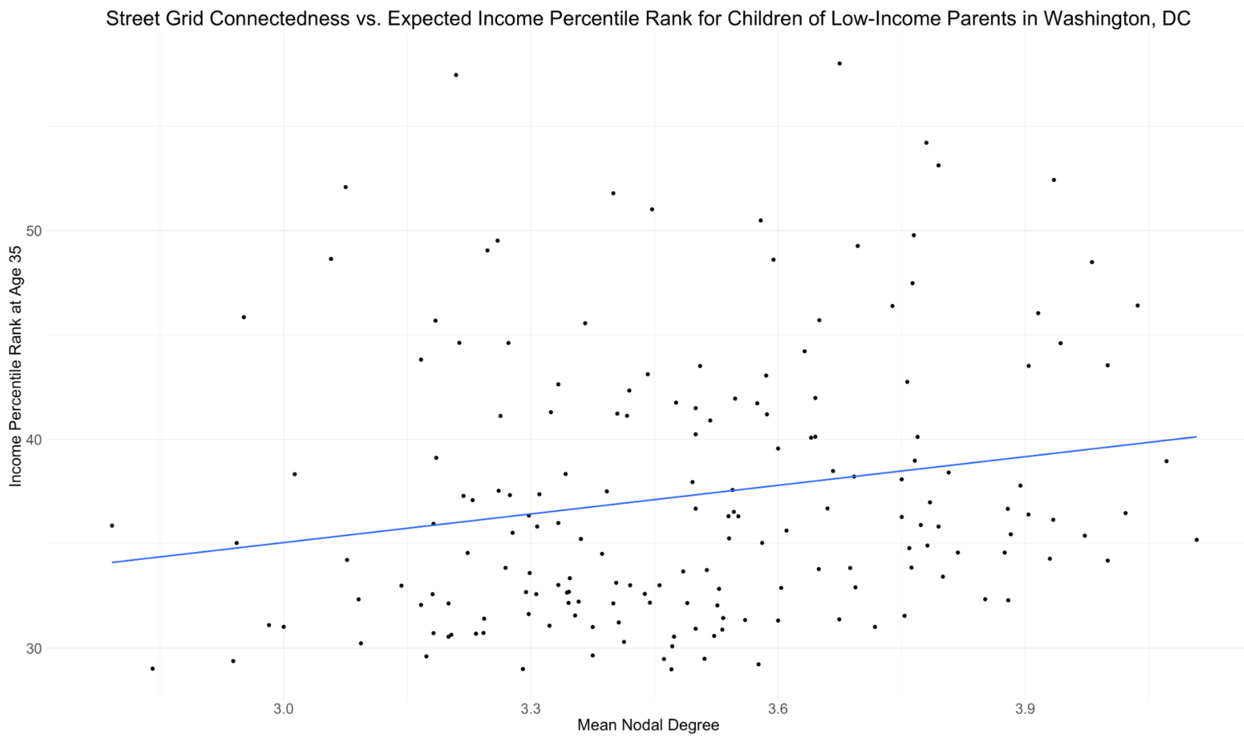

Figure 5. Scatter plot of tracts and single-variable regression between mean nodal degree and absolute mobility at the 25th percentile in Washington, DC.

Of course, this is an interesting observation, but the mild relationship could well be distorted by confounding variables which correlate strongly with mean nodal degree that themselves are driving the difference in economic outcomes. To rule this out or control for those variables in the case that there is covariance, a series of correlational tests can be performed. Chetty et al. (2018) find significant associations between expected income percentile rank in adulthood and key socioeconomic characteristics of a tract including the share of single-parent households, mean income, and the employment rate. They also find significant heterogeneity in the effect of these and other factors across racial subgroups. Based on this research, these are the key variables[4] for which correlation with mean nodal degree was tested (see Figures 6–8).

[4] To best align to the 1999 street network data, the socioeconomic characteristics from the 2000 decennial census were used when possible.

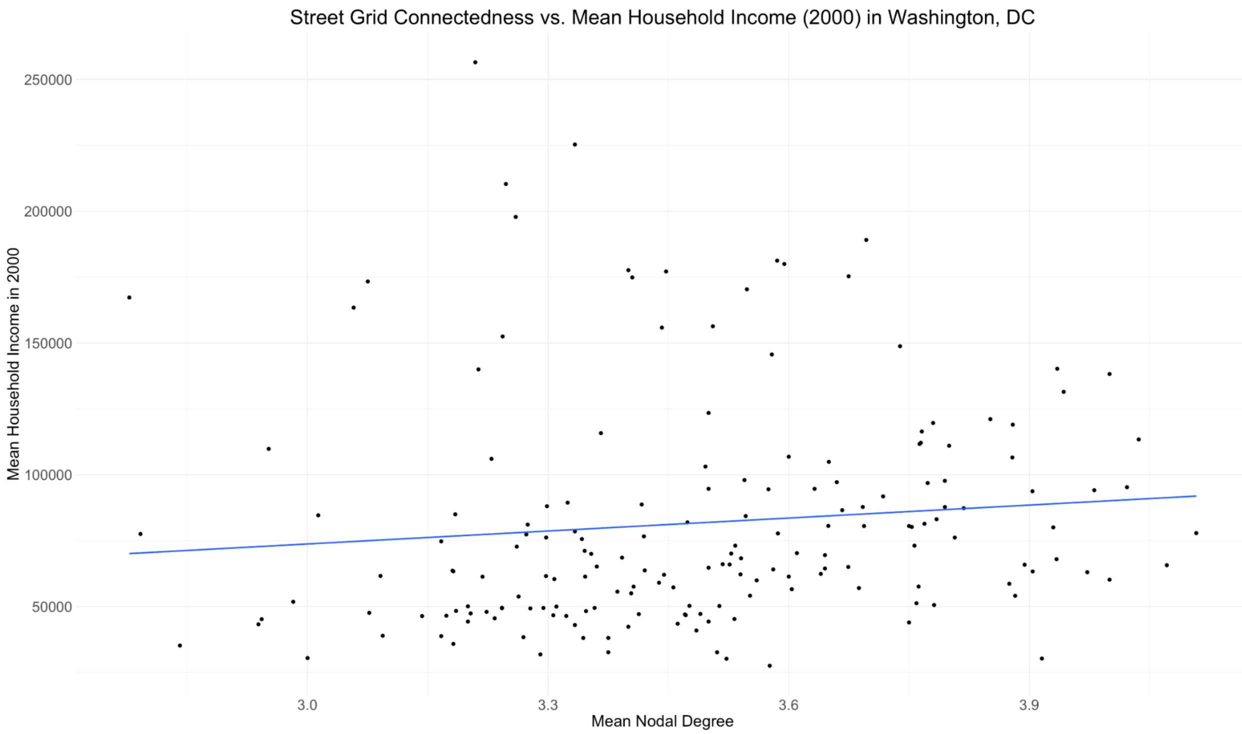

Figure 6. Association between mean household income and mean nodal degree in Washington, DC census tracts

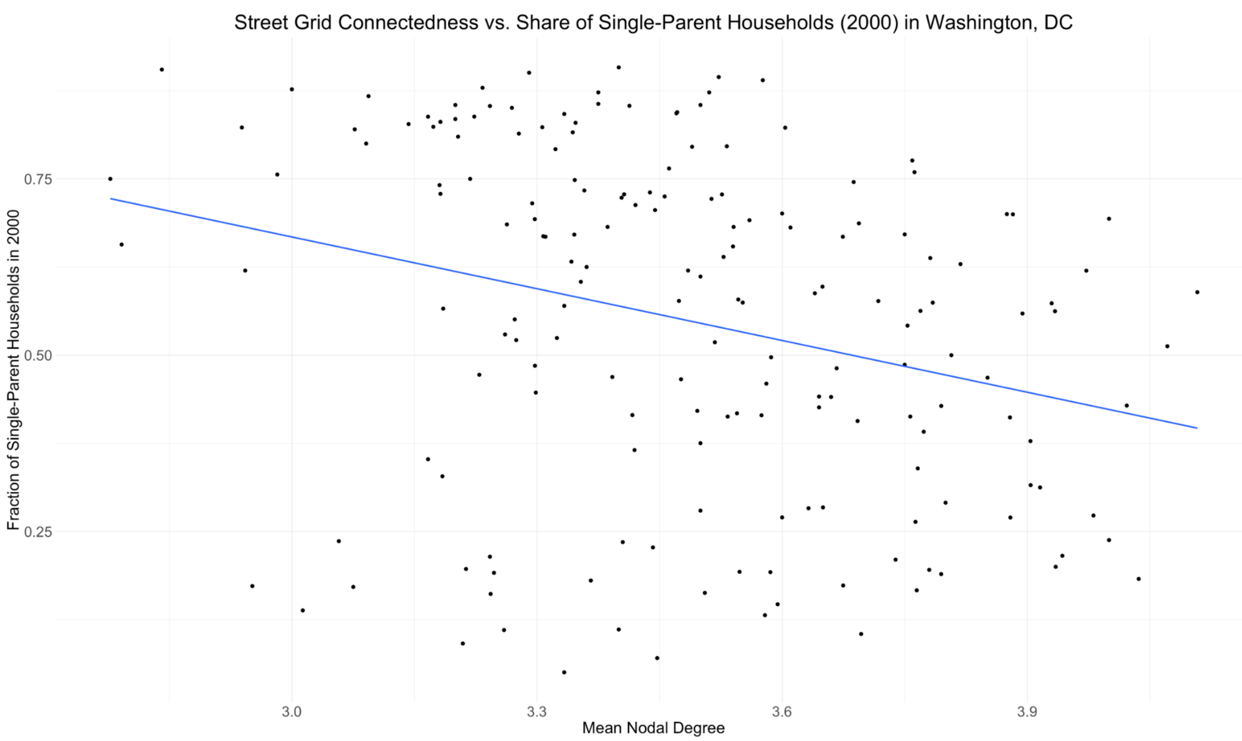

Figure 7. Association between the share of single-parent households and mean nodal degree in Washington, DC census tracts

Figure 8. Association between the employment rate and mean nodal degree in Washington, DC census tracts

From these three tests, two return significant correlations worth controlling for to improve model accuracy. The largest correlation coefficient found was between the employment rate and mean nodal degree at 0.344, with the correlation coefficient for share of single-parent households and street connectedness being -0.283, and least significantly the correlation coefficient for mean household income and mean nodal degree being 0.105. All of the correlation coefficients between the share of racial and ethnic subgroups (black, white, asian, and Hispanic) were between 0.2 and -0.2 which suggests little racial segregation by grid type or amount of connectedness. While it was initially hypothesized that grid connectedness could itself be a driver of some such socioeconomic factors, there is no reasonable case to be made that the design of the street network would impact the rates of single-parent households or the employment rate in a given area.

Two multivariable regression models were then prepared for comparison. The first controls only for the share of single-parent households and the employment rate in a tract, while the other accounts for those factors but also controls for the share of black, white, asian, and Hispanic residents in the tract (see Table 1). Perhaps as expected based on the significant correlation of mean nodal degree with other key correlates of absolute mobility at the 25th percentile, both models show that controlling for these socioeconomic and racial dimensions reduces the explanatory power of street grid connectedness on economic mobility to an insignificant level. Ultimately, it must be concluded that in these data the mean nodal degree of the street network in a given census tract is neither a strong correlate with nor a useful predictor of the expected income percentile rank at age 35 by children born to low-income parents.

Model 1 (Socioeconomic factors only) Coefficients

	Estimate	Std. Error	t-value	Pr(>|t|)
(Intercept)	53.96892	4.03117	13.388	<2e-16 ***
avg_node_degree	-1.15592	1.03998	-1.111	0.268
singleparent_share2000	-22.90396	1.60097	-14.306	<2e-16 ***
emp2000	-0.08181	2.75322	-0.030	0.976

Multiple R-squared: 0.7051, Adjusted R-squared: 0.6999 p-value: < 2.2e-16

Model 2 (Socioeconomic and racial/ethnic factors) Coefficients

	Estimate	Std. Error	t-value	Pr(>|t|)
(Intercept)	73.9445	33.1632	2.230	0.0271 *
avg_node_degree	-0.9344	1.0593	-0.882	0.3790
singleparent_share2000	-16.7578	2.3307	-7.190	2.3e-11 ***
emp2000	-3.6250	3.1325	-1.157	0.2489
share_black2000	-24.2269	33.2520	-0.729	0.4673
share_white2000	-20.1902	34.5289	-0.585	0.5595
share_hisp2000	21.0735	34.4097	-0.612	0.5411
share_asian2000	0.8208	37.0555	0.022	0.9824

Multiple R-squared: 0.7296, Adjusted R-squared: 0.7179 p-value: < 2.2e-16

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 1. Coefficients and summary statistics from two multivariate OLS regressions exploring the correlation between mean nodal degree and absolute mobility at the 25th percentile, while controlling for socioeconomic and racial differences between tracts

Despite these muted results, I still believe the relationship between urban design, neighborhood character, and economic opportunity is worth further analyzing. Looking beyond Washington, DC, it is worth noting the rough spatial similarities between the map of tract grid scores from Boeing’s analysis of tract grids (2021) and the map of household income for children born to low income parents from the Opportunity Atlas, particularly in the midwestern states (see Figures 9 & 10). Alternatively, perhaps the street grid is not the aspect of a neighborhood’s structure most impactful on its residents.

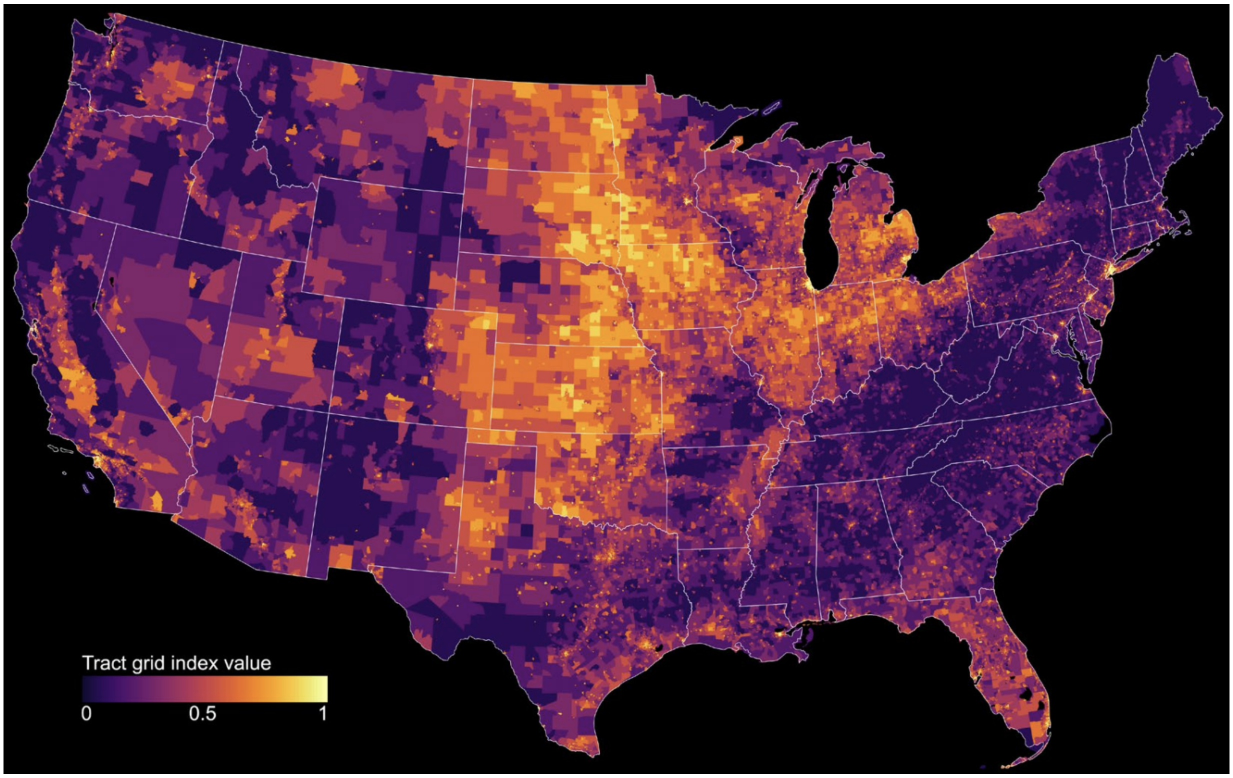

Figure 9. Map of tract grid index values across the contiguous U.S. (Boeing 2021, 12)

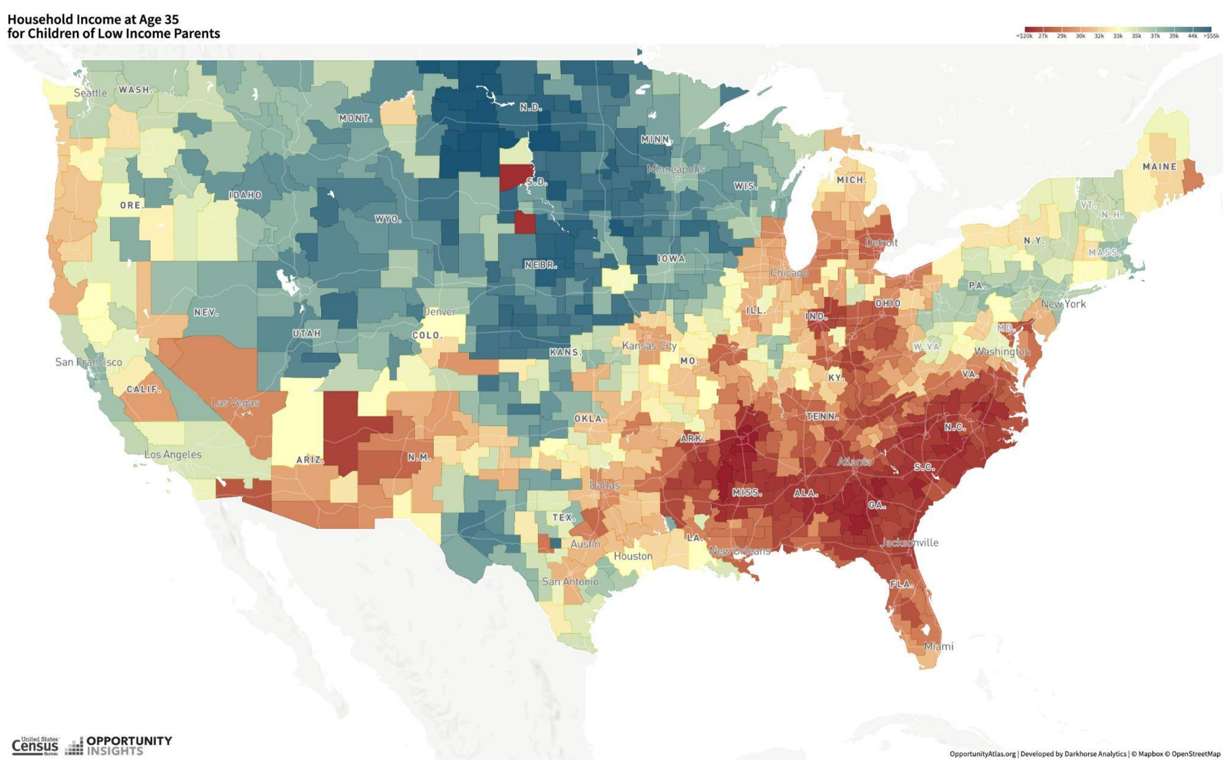

Figure 10. Map of Household Income at Age 35 for Children of Low Income Parents (Opportunity Atlas)

If research were to continue on the effect of street grid connectedness, a strong next step would be to expand the correlational analysis the whole of the United States looking at tract level mean nodal degree measures as calculated by Barrington-Leigh and Millard-Ball (2015), the tract grid index prepared by Boeing (2021), and potentially a categorical index such as neighborhood typology from Ralph et al. (2016). This broader study could either more thoroughly disprove any link between measures of street structure and economic outcomes, or begin to shine a light on where and when it might be influential.

Another line of deeper research relates to the findings by Chetty et al. (2022a) that social capital and particularly the socioeconomic status (SES) of friends in your network is a strong predictor of upward income mobility, and subsequently from Chetty et al. (2022b) that "the lowest-SES individuals make about four-times as large a share of their friends in their neighborhoods (residential ZIP codes) as the highest-SES individuals do." It would follow, then, that if the design of a particular neighborhood, like it's street network, had a measurable effect on its residents' social capital then those urban planning choices could be partial drivers or inhibitors of upward mobility, especially for lower-SES individuals who would feel the effects the most given their reliance on the neighborhood as a place to make connections. As previously noted, this idea that urban density and sprawl may be tied to social capital is one that has been put forth previously and contested hotly. With the new big data-enabled methods that the aforementioned studies leverage, perhaps there is an opportunity to make new strides in this familiar debate.

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