Freeway revolts!

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Abstract

Freeway revolts—mass protests by central-city residents concerned about local quality of life—erupted across the U.S. following early urban Interstate construction in the mid-1950s. We present theory and evidence showing that the concerns of the freeway revolts (namely, disamenities from freeways) were important for the eventual allocation of freeways within cities and changes in city structure. Using panel data on U.S. cities and neighborhoods between 1950 and 2010, we show that disamenity effects dominate access benefits in central cities: downtown neighborhoods closer to new highways declined more (or grew more slowly) in population, income, jobs, and land values compared with neighborhoods farther away. But in the suburbs, where access benefits are more important, proximity to a highway has the opposite effect. Further, actual freeway construction increasingly diverged from initial plans in the wake of the growing freeway revolts and subsequent policy responses, especially in central neighborhoods. We use a quantitative city structure model to quantify the effects of freeway disamenities and evaluate mitigation policies. The aggregate welfare benefits from burying or capping highways are large and concentrated downtown, explaining political opposition to urban freeways.

Keywords: central cities, urban growth, amenities, commuting costs, suburbanization, highways
JEL classification: R14, R23, N92, O18

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1 Introduction

The Federal-Aid Highway Act of 1956 authorized and financed the Interstate Highway System, with the ambitious goal of completing 41,000 miles of freeways by 1969. Early freeway building was fast. As they moved to build the Interstates in 1956, highway planners faced little early opposition and few constraints. The prevailing view among engineers, policy makers, and the public was that highways would ease congestion and revitalize downtowns. Lewis Mumford, later an important critic of urban freeways, initially "viewed the automobile as a beneficient liberator of urban dwellers from the cramped confines of the industrial city" (DiMento and Ellis, 2013, p. 38).

But mass construction soon led to skepticism, especially among residents of dense urban areas, then outright protest. *Freeway revolts* soon spread to at least 50 U.S. cities. A short-lived U.S. Department of Transportation (DOT) survey between October 1967 and June 1968 recorded 123 separate freeway revolts (Mohl, 2002), and in just a single month, March 1968, a DOT official noted "problems of a serious nature in at least 25 cities" (Mohl, 2008, p. 202). These freeway revolts pitted central-city residents concerned about local quality of life against regional planners who saw expanding transportation networks as key to regional growth. (Famously, neighborhood advocates including Jane Jacobs fought the construction of central-city freeways such as the Lower Manhattan Expressway.) Mass construction had sharpened the side effects of freeways in the public imagination—e.g., land taking, negative externalities from pollution and noise, and barriers between neighborhoods. In response, policy gradually ceded more control to local neighborhood concerns. In San Francisco, an early center of the freeway revolts, the Board of Supervisors halted further freeway construction in January 1959, leaving the Embarcadero Freeway—and most of the planned freeway network—permanently unfinished. Across the U.S., aided by federal highway legislation in 1962 and 1966 and other policy changes in the 1960s, protestors often significantly altered, or stopped outright, proposed freeway routes.

What factors motivated the freeway revolts? How did the revolts and subsequent policy responses shape the allocation of freeways in U.S. cities? And how, and why, did freeways affect the shape of U.S. cities? In this paper, we shed light on the causes and the consequences of the freeway revolts. A central theme is that—aside from reducing travel costs—freeways produce local disamenities that significantly reduce neighborhood quality of life. These disamenities disproportionately affected central city neighborhoods, with important implications for both the eventual allocation of highways within cities and the spatial structure of U.S. cities today.

First, we present theory and evidence highlighting the disamenity effects of highways on city structure. Using panel data on U.S. cities and neighborhoods between 1950 and 2010, we show that downtown neighborhoods closer to newly-opened highways declined more in population and income compared with neighborhoods farther away. But in the suburbs, proximity to a highway has no such effect. Intuitively, in downtown neighborhoods, the disamenity value of a new highway dominates its access benefits. But in outlying neighborhoods, access benefits are greater. These findings can be easily explained by disamenity effects but are more difficult to reconcile with standard city structure models that focus exclusively on highways' effects on reducing access costs.

To identify the causal effect of highways on neighborhoods in the context of the endogenous allocation of highways to cities and neighborhoods, we use planned-route and historical-route instrumental variables (following the typology of Redding and Turner, 2015). The IV results suggest a strongly negative causal effect of highways on population in central cities. We also show evidence from historical travel survey data from Chicago and Detroit that employment declined faster near freeways in downtown neighborhoods. Thus, increases in firm demand for downtown land near freeways seem unlikely to be driving population and income declines near downtown freeways. In Chicago, appraised land values also grew more slowly near downtown freeways, again consistent with freeway disamenities and not with freeway-related productivity gains. We also show evidence of barrier effects—that is, increases in the cost of travel *across* a freeway—from newly-rediscovered travel diary microdata from Detroit in 1953 and 1994. Travel flows decline, and travel times increase, for trips up to 3 miles crossed by new highways. These estimates take into account changes in the desirability of neighborhoods as origins or destinations caused by highway construction and fixed characteristics of neighborhood pairs using high-dimensional fixed effects in a "structural gravity" model (Head and Mayer, 2014).

Second, we analyze the consequences of the freeway revolts on the allocation of freeways to U.S. cities and neighborhoods. The revolts were a surprise to highway engineers and planners as they began building the Interstates in the middle 1950s. As the revolts spread, federal and state policy evolved to better accommodate protestors' concerns. For example, the 1958 highway act first required state highway officials to hold at least one public hearing and consider economic effects in advance of construction. Subsequent legislation in 1962, 1966, 1968, and oversight by the new Department of Transportation beginning in 1967 added additional constraints on state highway departments. Thus, highway segments that were completed early, in the late 1950s, tended to follow planned routes, while highway segments that were delayed into the 1960s were more likely to be altered in routing or canceled entirely in the face of opposition. We find that compared with 1955 planned routes, the realized highway network of the late 1960s was more likely to be aligned near coasts, rivers, and historical rail roads. These patterns are consistent with the increasing challenges faced by highway builders in acquiring rights of way. The increasing divergence of the built freeway network from initial plans was especially true in central cities, highlighting both the intensity of protests in downtown neighborhoods as well as their success in diverting planned freeways. Further, better-educated and more-white neighborhoods were increasingly more successful at avoiding planned freeway construction over the 1960s. These groups may have been better able to take advantage of new freeway-fighting policies, a political economy channel emphasized by Glaeser and Ponzetto (2017).

Third, we develop a quantitative spatial general equilibrium model of city structure to measure and quantify the effects of freeway disamenities. The model builds on the existing class of quantitative urban/trade models that consider the joint location decisions of employment and population in a city with costly commuting, including recent work by Ahlfeldt, Redding, Sturm, and Wolfe (2015); Allen, Arkolakis, and Li (2015); Monte, Redding, and Rossi-Hansberg (2015); and Sev-

eren(2016).[1] The model explicitly takes into account several features that are less well-handled by the reduced-form techniques, including spillovers between neighborhoods, endogenous employment location, and general-equilibrium effects. By using observed travel times with the structure of the model, we also take into account the variation in treatment intensity caused by the radial freeway networks that concentrate freeways downtown. We calibrate our model to match cross-sectional variation within the Chicago metropolitan area in the year 2000 in neighborhood population, employment, and travel times. We use residual neighborhood amenities recovered from the structure of the model to estimate the disamenity that arises from proximity to a freeway. In our baseline calibration, we estimate neighborhood amenity is 21 percent lower next to a freeway, and this disamenity attenuates by 95 percent at three miles' distance. Intuitively, this disamenity is identified by freeway-adjacent neighborhoods that have superior access (low travel times to employment centers) but low populations. This result is robust to alternative calibrations and instrumental variables estimates.

We use the quantitative model to consider a counterfactual experiment in which freeway disamenities are mitigated. This policy is analogous to real-world policies like the "Big Dig" that attempt to mitigate the negative effects of freeways by burying or capping them. In our baseline calibration, the aggregate benefits are large and concentrated near downtown. The concentration of mitigation benefits downtown (or the concentration of disamenities downtown) follow from two factors: One, downtown highways affect more people, due to higher population densities, and two, there are more highways downtown, due to the radial design common to most U.S. metropolitan areas. This result helps explain why the freeway revolts—and political opposition to freeways in general—were concentrated in central city neighborhoods.

1.1 Related work

Our paper makes contributions to several literatures. First, a large literature estimates the effects of highways on economic geography (Chandra and Thompson, 2000, Michaels, 2008, Allen and Arkolakis, 2014). For example, Duranton and Turner (2012) estimate the impact of Interstate highways on the distribution of employment across cities, and Baum-Snow (2007) estimates the effects on highways on the movement of population from central cities to the suburbs. Traditionally, economists have understood these highway effects through the channel of reduced costs of transporting goods and people (see the review by Redding and Turner, 2015). Our paper contributes to this literature by emphasizing that highways also affect the spatial organization of economic activity by changing relative amenity values. Further, we provide evidence at a finer spatial scale (census tracts or neighborhoods) compared with previous work.

A large literature examines the decentralization of U.S. cities. Previous papers have highlighted highways' effects through reducing commuting costs (LeRoy and Sonstelie, 1983; Baum-Snow, 2007; Kopecky and Suen, 2010). As Duranton and Puga (2015) note, while the relative decline of central cities in response to lower transportation costs is consistent with the monocentric city

[1] For surveys of the literature see Redding and Rossi-Hansberg (2017); and Holmes and Sieg (2015).

model, it is more difficult to rationalize the large *absolute* declines in central city population. Margo (1992) and Kopecky and Suen (2010) have appealed to increases in household incomes to fill this gap. White flight in response to African-American migration to northern cities (Boustan, 2010) and the 1960s riots (Collins and Margo, 2007) also contributed to declines in central city populations. Our contribution is to identify the disamenity effects of highways, apart from their effects in reducing commuting costs, as an important contributor to the decentralization of cities. In our analysis, freeways have disproportionately negative effects in central cities because (i) these areas see relatively less improvement in access and (ii) these areas receive more freeways due to the radial design common to most U.S. city freeway networks.

There is a large body of work on negative externalities of highways. For example, Anderson (2016) identifies increased mortality from particulate pollution among elderly residents near highways using wind patterns. Other recent papers evaluating negative externalities from highways include Hoek et al. (2002), Gauderman et al. (2007), Currie and Walker (2011), Rosenbloom et al. (2012), and Parry, Walls, and Harrington (2007). Much of this literature considers the effects of highways on housing or land prices. Our paper adds to these results by considering their implications for the spatial structure of cities, i.e., quantities. In addition, another contribution is that we provide evidence that highways create barriers between neighborhoods. This evidence is from newly-rediscovered travel diary microdata from Detroit in 1953 (and a follow-up survey from 1994) that was famously used in Kain's (1968) study of spatial mismatch.

Finally, there is a small literature on the political economy of infrastructure investment (Knight, 2002; Altshuler and Luberoff, 2003; Glaeser and Ponzetto, 2017). We add to this literature by providing evidence on the types of neighborhoods that received urban freeways in the 1950s and 1960s, and by showing changes over time in these patterns.

2 The effects of highways on cities

In this section we more precisely describe the effects of constructing a freeway in a city, taking into account both the benefits from increased access and the costs due to the disamenity effects for neighborhoods near the freeway. [2] To fix ideas, consider the the classic monocentric model of a city developed by Von Thunen (1826), Mills (1967), and others. In this model, all employment is located in a central business district (CBD) and is surrounded by residential locations where employees live. Given that commuting is costly, this model predicts that both population density and land prices decline away from the CBD. Workers thus face a tradeoff in location decisions between higher land prices and shorter commutes, and in equilibrium, prices will adjust such that utility is equalized at every location in the city.

When a highway is constructed that connects the CBD to outlying areas there will be several effects. The first well-known effect is that access to the CBD will increase through faster commutes. In addition, the access benefits from this highway are not the same for every location. Locations

[2] Here, we discuss a simle model of a city to provide intuition. A more rigorous model of city structure and highways is presented in Section XX.

near the CBD will not benefit significantly, given that the addition of the highway has little effect on commuting costs. Locations far from the CBD potentially benefit, but only if they are near the freeway. Therefore, when a freeway is built, access benefits cause relative population growth in locations that are farther from the CBD and closer to the freeway. Overall, the result is population growth and decentralization, with the distribution of the population spreading out along the newly constructed highway. Note that this analysis pertains not only to a CBD, but can be applied more generally to any regional amenity that will be more accessible with the addition of a freeway.

The second effect of freeway construction in cities, which is a primary focus of this paper, are the costs or disamenities that emerge in neighborhoods near the highway. These disamenity effects may stem from several sources including loss of developable land, pollution or noise externalities, or barrier effects, where access is reduced to neighborhood-level amenities. These costs may arise in all locations in the city, independent of proximity to the CBD. Therefore the net effect of both the access and disamenity effects of highways on population growth will vary by location. Specifically, for neighborhoods near the CBD, given that improvements in access are minimal, the disamenity effects will dominate, and population growth will be lower in neighborhoods near the freeway. For locations far from the CBD, the net effects of highways are ambiguous. If the access benefits dominate the disamenity effects, then population growth will be larger near the freeway in outlying areas. Unambiguously, the growth in population near the freeway will be relatively larger in outlying areas compared to neighborhoods near the CBD

In sum, this discussion provides testable implications for the importance of the highway disamenity effects. First, for locations near the CBD and near a freeway, we would expect to see strict population decline after a freeway is built. This is due to the fact that locations near the CBD get no commuting benefits from the freeway, and instead only experience a disamenity. Second, for locations near the CBD we would expect that the decline in population would be less at locations further from the freeway. There is no benefit from being close to the freeway near the CBD, only disamenity, but the disamenity effect attenuates at locations further from the freeway. Third, for locations further from the CBD, proximity to the freeway becomes more beneficial due to the access benefits, and locations near the freeway could see higher population increases relative to those further from the freeway.

Finally, there are also implications for the sorting of income groups within a city. The sorting effects can be ambiguous and will depend on the sources of heterogeneity among income groups. In particular, the predictions depend on the relative importance of amenities among income groups[3] and the form of the commuting technology.[4] In general, the effects on sorting are similar to the effects on population. If there is a disamenity effect from being located close to the freeway, then it will be more important for sorting in neighborhoods near the CBD. In suburban neighborhoods, the sorting patterns after freeway construction will depend more on the reduced commuting costs. The

[3]Several papers have shown that preferences for amenities increase with skill or income, including, Lee and Lin (2015), Lee (2008), Handbury (2012), Brinkman (2016), and Diamond (2016).

[4]In particular, results may vary depending on whether or not commuting costs scale with income and the importance of fixed costs as studied by LeRoy and Sonstelie (1983).

fact that there are potentially multiple sources of heterogeneity makes overall patterns ambiguous. We will use the empirical results to shed some light on the important sources of heterogeneity that lead to changes in sorting after freeway construction.

3 Data

- Population, income, etc. for consistent-boundary census tracts from Lee and Lin (2017).
- Metropolitan areas are CBSAs as defined in 2010.
- City centers identified using the 1982 Census of Retail Trade, following Fee and Hartley (2013)
- Limited access highway shapefiles from the National Highway Planning Network (NHPN) (2016), a GIS database containing line features representing highways in the United States. We use all segments designated as limited access.
- PR-511 database provides opening dates for each interstate highway segment, up until 1993. A digitized version of these data and a corresponnding shapefile were provided by Nate Baum-Snow. We did some further cleaning of these data. Note that Interstates are a subset of the NHPN database of limited-access roads.
- Planned-route IV: We digitized the 1947 interstate highway plan, following Baum-Snow (2007). "National System of Interstate Highways selected by joint action of the several state highway departments as modified and approved by the administration, federal works agency, August 2, 1947," Public Roads Administration, Federal Works Agency (1947). We also constructed an alternate version of this instrument by connecting all city pairs via shortest-path routes. City pairs were selected using any 2 cities connected by the 1947 plan without going through an named intermediate third city.
- Historical-route IV: We used historical rail routes 1890 and earlier from Jeremy Atack (2016). We digitized historical exploration routes from the National Atlas (1970), following Duranton and Turner (2012).
- Note that we re-digitized highway and instrument maps because previous used data suitable only at across-metro resolution.
- Trip data from historical and modern travel surveys from Detroit (1953, 1994) and Chicago (1956), as well as the Census Transportation Planning Product from 2000.
- Appraised land values for 300×300 foot grid cells in Chicago from *Olcott's Blue Books* in 1949 and 1990, shared by Gabriel Ahlfeldt (Ahlfeldt and McMillen, forthcoming).
- Planned intra-city Interstate routes are from the "General Location of National System of Intestate Highways" (1955), commonly known as the "Yellow Book." These plans from 1955

were the first within-metropolitan area plans for the location and routing of highways. We digitized these maps for this project.

4 Evidence of freeway disamenities

In this section, we evaluate the predictions of the theory presented in section 2. First, we consider the effects of freeway construction on long-run neighborhood growth between 1950 and 2010. (This brackets the period of major freeway construction between 1956 and 1980.) We find that: (i) central cities experienced absolute declines in population, (ii) outlying areas experienced large increases in population, (iii) among central neighborhoods, those assigned new freeways saw larger population declines, and (iv) among outlying neighobrhoods, those assigned new freeways saw larger population increases. To address the endogenous allocation of freeways to neighborhoods, we use proximity to planned and historical routes as instruments. Further, the pattern of population changes is similar with respect to an exogenous regional amenity instead of the central business district: among coastal neighborhoods, those assigned new freeways saw larger population declines; among interior, non-coastal neighborhoods, those assigned new freeways instead saw larger population increases. We also find weakly similar patterns using long-run changes in income, where the theoretical predictions are less clear. Finally, using data from 1950s travel surveys conducted in the Chicago and Detroit metropolitan areas, we find that that job growth was not significantly faster near dowtown freeways. Further, travel volumes declined and travel times increased between tract pairs up to 3 miles apart when tract pairs were severed by newly constructed freeways.

4.1 Population growth

We begin by examining descriptive evidence from the Chicago metropolitan area. Figure 1 displays a map of 1950–2010 changes in census tract population, in natural logarithms. (Historical data is normalized to 2010 tract boundaries so that land area is held constant. Our analysis uses only tracts with available data in both 1950 and 2010.) Shades of orange indicate absolute declines; shades of blue indicate absolute increases in density. The highway network (red) is mostly radial, with several beltways. The radials converge on the "Loop", or the central business district, which today accounts for about half of the jobs in the City of Chicago and about 17 percent of all jobs in the metropolitan area.

Several features are worth noting. First, peripheral areas (that is, peripheral as of 1950) gained significant population compared with central neighborhoods. This is consistent with the standard prediction of the monocentric city model, as travel costs declined more in the suburbs. Second, areas near the CBD experienced large *absolute* population losses. As noted earlier, this might indicate declines in neighborhood amenities. Third, in central areas just outside the CBD, population declines appear larger in neighborhoods near freeways. Fourth, in contrast, the pattern is less clear in peripheral neighborhoods, though in some cases neighborhoods near freeways seem to have experienced larger population increases compared with those farther away.

Figure 2 summarizes these patterns for all census tracts in all 64 metropolitan areas in our sample. For this exercise, we separated the tract sample into four bins by distance to the city center: 0–2.5 miles, 2.5–5 miles, 5–10 miles, and more than 10 miles from the city center. (Of the 64 metropolitan areas in our sample, 38 have tracts beyond 10 miles.) Each line in panel (a) shows kernel-weighted local polynomial smooths of the 1950–2010 change in the natural logarithm of consistent-boundary tract population. (To account for variation across cities in overall population growth, tract changes are centered around their metropolitan area means.) Each smooth ends at the 99th percentile consistent-boundary tract by distance to the nearest freeway, so e.g., 99 percent of tracts within 2.5 miles of the city center are within 2.8 miles of a freeway. Panel (b) shows that the median sample tract is quite close to a freeway: near city centers, over three-quarters of tracts are within 1 mile of a freeway. Even for tracts more than 10 miles from city centers, half are within 1 mile of a freeway.

These smooths confirm the patterns observed in the Chicago metropolitan area and are consistent with our theoretical predictions. Population declines near city centers and increases in suburban areas following freeway construction. For neighborhoods within 5 miles from city centers, proximity to a freeway is negatively correlated with population growth, consistent with the idea that small access benefits are dominated by freeway disamenities. For neighborhoods farther than 5 miles from city centers, proximity to a freeway appears positively correlated with population growth, pointing to greater net benefits from freeways.

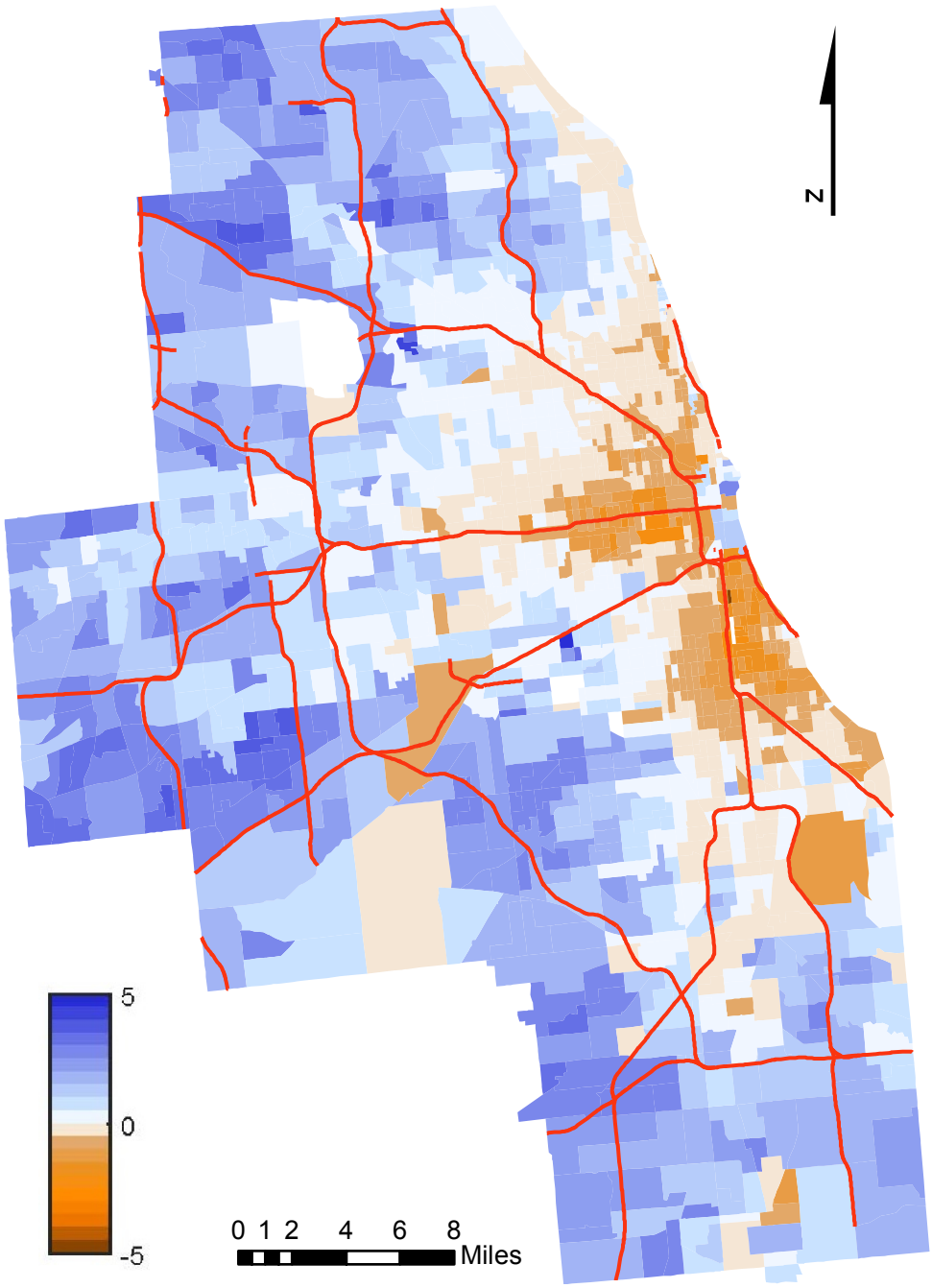
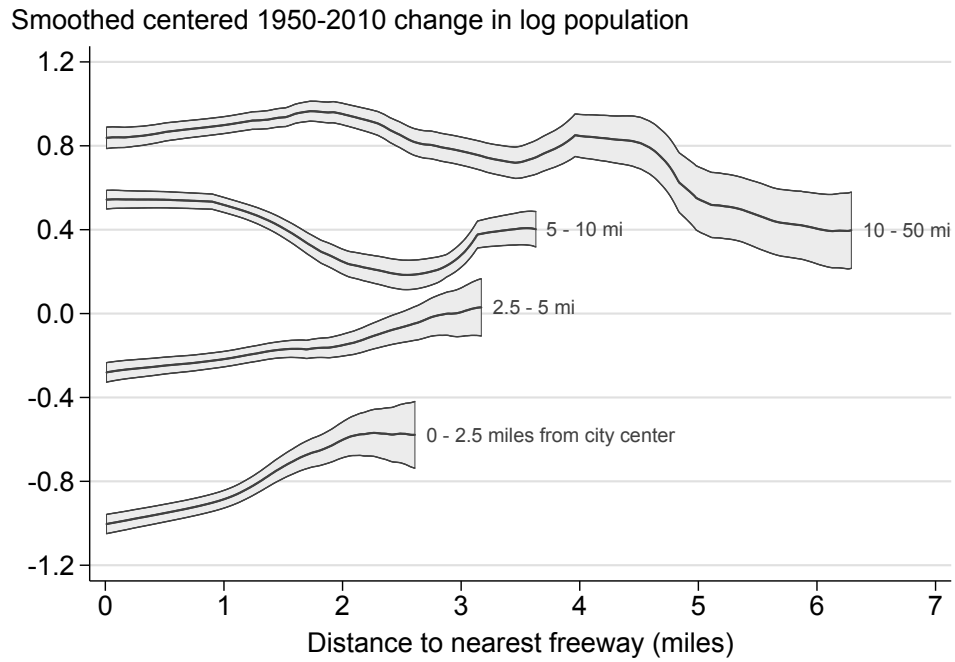


Figure 1: Central neighborhoods declined in population, especially near freeways

This map shows 1950–2010 changes in the natural logarithm of population for consistent-boundary census tracts in the Chicago metropolitan area. The geographic extent is determined by census tract data availability in 1950.

(a) Change in population by distance to freeway and distance to city center



(b) Cumulative distribution of neighborhood distance to freeway

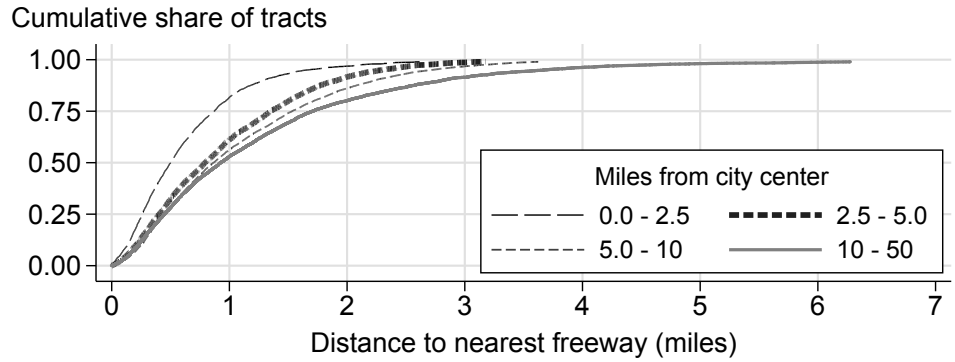


Figure 2: Freeway neighborhoods declined in city centers and grew in the periphery

The plots in panel (a) show kernel-weighted local polynomial smooths of the 1950–2010 change in the natural logarithm of consistent-boundary tract population for neighborhoods in 64 metropolitan areas. Changes in log population are centered around their metropolitan area means. Each line represents smooths for a separate subsample conditioned on distance to the city center, as indicated by the line labels. Smooths use Epanechnikov kernel with bandwidth 0.5 and local-mean smoothing. Shaded areas indicate 95 percent confidence intervals. Each smooth ends at the 99th percentile consistent-boundary tract by distance to the nearest freeway. Panel (b) shows the empirical cumulative distribution of census tracts by distance to the nearest freeway and distance to the city center.

4.2 Estimation and identification

Next, we can more formally analyze the patterns shown in Figure 2 with the following regression:

$$\Delta n_{g[m]} = \alpha_m + \beta_1 d_F + Z_g'\gamma + \epsilon_g \tag{1}$$

Here, $\Delta n_{g[m]} \equiv \log n_{g,2010} - \log n_{g,1950}$ is the change in the natural logarithm of population between 1950 and 2010 for neighborhood g in metropolitan area m. d_F is the distance from the neighborhood centroid to the nearest freeway, and Z_g is a vector of controls measuring fixed and persistent neighborhood factors. A metropolitan area fixed effect α_m ensures that identification comes from variation across neighborhoods, within metropolitan areas, in proximity to the realized highway network.

We run this regression separately for subsamples conditioned on distance to the city center—i.e., neighborhoods within 2.5 miles of the city center, neighborhoods between 2.5 and 5 miles from the city center, neighborhoods between 5 and 10 miles from the city center, and neighborhoods more than 10 miles from the city center. This flexible specification allows us to test whether the effects of freeway construction on neighborhoods vary by proximity to the city center. The key test of the disamenity effect comes from the coefficient on distance to the highway, d_F, as noted in Proposition **??**.[5] Through the lens of model, β_1 will be positive for central neighborhoods only if there is a disamenity from being located near a highway. A positive coefficient means that holding all else equal, downtown neighborhoods farther from the freeway experienced higher population growth.

Table 1, panel (a) shows weighted least-squares estimates of equation (1), where individual tract observations are weighted by the inverse of the number of tracts in the metropolitan aera. (These weights ensure that large metropolitan areas with many tracts have less influence over the results. We show similar results later without weights.) Each column is a separate regression, using tracts conditioned on distance to the city center identified by the column title. The coefficient estimates have the expected sign and are precisely estimated. The coefficient on miles to freeway can be interpreted as the additional percentage growth in population for each additional mile a tract is located from the highway. For tracts closest to the city center, this effect is positive, meaning that tracts 1 mile from a freeway at the city center grew 24 percent more compared with those located at next to the freeway. (A positive coefficient means that population declines are larger, or population increases are smaller, closer to freeways.) This is the key test of the theory. Additionally, looking across columns, this effect declines with distance to the city center. At 5 miles and more removed from the city center, tracts closest to freeways increased more in population compared with tracts farther from freeways. This is consistent with the idea that the relative importance of access versus amenity varies from the suburbs to the city.

The second row reports the estimated average metropolitan area fixed effect. This estimate can be interpreted as the average change in population for the subsample tracts conditioned on the distance to the city center noted in the column title and zero distance to the nearest freway.

[5] A disamenity would be also be consistent with the overall decline in population in the center of the city (Proposition **??**).

Table 1: Freeway neighborhoods declined in city centers and grew in the periphery (WLS estimates)

	(1)	(2)	(3)	(4)
	Distance to city center:			
	0–2.5 miles	2.5–5 miles	5–10 miles	10–50 miles
(a) WLS estimates				
Miles to nearest freeway	0.241^{c}	0.118^{c}	-0.156^{b}	-0.072
	(0.076)	(0.034)	(0.075)	(0.059)
Average metro FE ($\bar{\alpha}_{.}$)	-0.677^{c}	0.075^{b}	1.091^{c}	1.634^{c}
	(0.049)	(0.033)	(0.091)	(0.099)
R^2	0.026	0.011	0.019	0.008
Neighborhoods	2,312	3,482	5,561	5,173
Metropolitan areas	64	63	56	38
(b) ... with controls for natural and historical factors				
Miles to nearest freeway	0.257^{c}	0.110^{c}	-0.187^{b}	-0.033
	(0.067)	(0.033)	(0.072)	(0.038)

Notes: This table shows WLS estimates of equation (1). Each panel–column reports a separate regression. Neighborhoods are weighted by the inverse number of neighborhoods in the metropolitan area. All regressions include metropolitan area fixed effects. Estimated standard errors, robust to heteroskedasticity and clustering on metropolitan area, are in parentheses. ^{a}—$p < 0.10$, ^{b}—$p < 0.05$, ^{c}—$p < 0.01$. Regressions reported in panel (b) include controls for neighborhood proximity to nearest park, lake, seaport, river, coastline, and city center in miles, and four categories indicating average neighborhood slope.

Thus, freeway tracts within 2.5 miles of city centers declined 68 percent in population, while tracts outside 2.5 miles from city centers increased in population. These patterns are also consistent with the predictions of the model.

Panel (b) shows estimates adding controls for natural and historical factors: tract distance to the nearest river, lake, coastline, seaport, city center, and 4 separate dummies for average tract slope. The estimated coefficients on freeway proximity are unaffected by the inclusion of these controls.

Of course, highways are not allocated randomly to neighborhoods. There may be two possible selection margins. First, highways might be targeted to neighborhoods with greatest growth potential in order to maximize the benefits of public investment. On the other hand, highways might be routed through neighborhoods with less growth potential, perhaps for political economy reasons. Existing evidence on selection, at the municipality or metropolitan area level, is mixed. For example, Duranton and Turner (2012) find evidence that slow-growing or shrinking metros were allocated more highways. Other studies (Baum-Snow et al. 2012, Garcia-Lopez et al. 2013) suggest the opposite. Our analysis departs from earlier studies in that we consider the allocation of freeways to small geographic units—census tracts—compared with municipalities or larger regions.

We follow the literature on causal identification of highway effects including research by Chandra and Thompson (2000), Baum-Snow (2007), Michaels (2008), and Duranton and Turner (2012). We use both planned routes and historical routes as instruments for actual freeway routes, following

the typology of Redding and Turner (2015). We use neighborhood proximity to routes shown in the 1947 highway plan as an instrument for proximity to an actual limited-access freeway. As argued by Baum-Snow (2007), the objective of the 1947 plan (Figure 3) was to improve travel *between* distant cities and national defense. Thus, the plan is unlikely to be correlated with neighborhood growth factors. In fact, the planned routes were drawn at national, not regional or metropolitan, scales, so the routing of planned highways within metropolitan areas is determined by the number and orientation of nearby large metropolitan areas. For example, the north-south orientation of I-35 through Austin, Texas, was predicted by the orientation of Austin compared with Dallas (north) and San Antonio (south), rather than neighborhood-specific factors.

We also experiment with a variant of this instrument that instead connects via shortest-distance routes all city center pairs connected by the 1947 plan without going throgh an intermediate third city. This variant is correlated with the planned route instrument, except when a "curved" plan route is "straightened out." For example, the actual planned route between Las Vegas and Salt Lake City displays a notable curve; a second instrument shifts this route westward and northward to minimize the distance between the two cities.

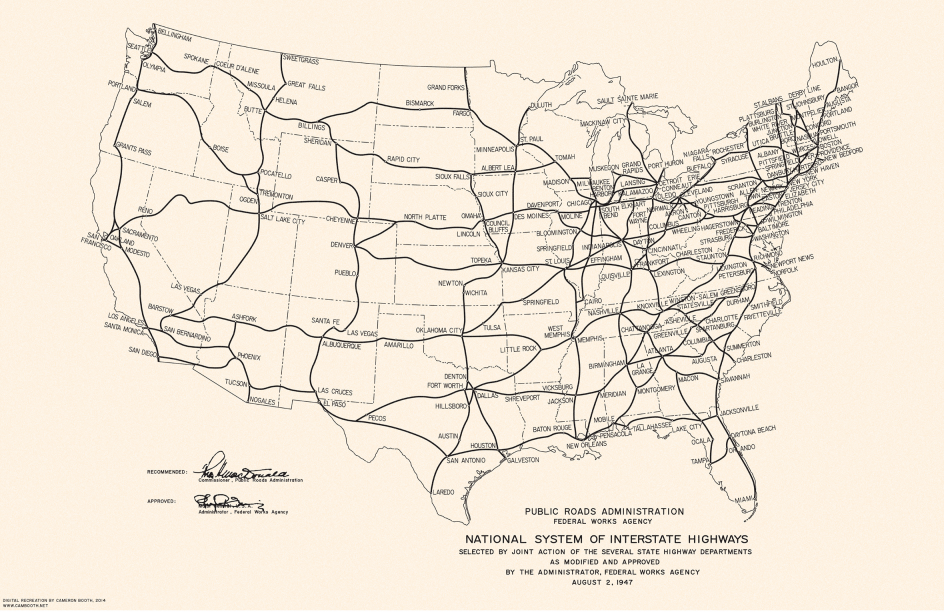


Figure 3: 1947 highway plan

We also use neighborhood proximity to historical routes as instruments. Identification relies on the fact that historical transportation routes, such as explorers' paths or rail lines, are unlikely to be correlated with current neighborhood characteristics. These routes are likely low-cost locations either due to topography (first nature) or for land assembly reasons (second nature). Following Duranton and Turner (2012), we use exploration routes in the 16th–19th centuries, digitized from

the National Atlas (1970), and historical railroads in operation by 1898 by Atack (2016).[6]

Table 2: Freeway neighborhoods declined in city centers and grew in the periphery (IV estimates)

	(1)	(2)	(3)	(4)
	Distance to city center:			
	0–2.5 miles	2.5–5 miles	5–10 miles	10–50 miles
(a) IV estimates using 1947 inter-city plan and shortest-distance routes				
Miles to nearest freeway	1.751[c]	0.712[c]	0.377	0.029
	(0.342)	(0.241)	(0.408)	(0.194)
Kleibergen-Paap LM test (p)	0.000	0.001	0.045	0.097
Cragg-Donald Wald stat (F)	53.4	61.9	61.6	105.1
Kleibergen-Paap Wald stat (F)	12.6	9.9	3.9	3.5
Hansen J test (p)	0.988	0.124	0.128	0.563
(b) IV estimates using pre-1898 railroad and 16th-19th c. exploration routes				
Miles to nearest freeway	1.004[c]	0.851[c]	0.905	0.292
	(0.277)	(0.243)	(0.566)	(0.241)
Kleibergen-Paap LM test (p)	0.000	0.001	0.009	0.033
Cragg-Donald Wald stat (F)	154.3	107.3	45.4	150.7
Kleibergen-Paap Wald stat (F)	26.2	11.2	5.0	5.3
Hansen J test (p)	0.704	0.129	0.540	0.536
(c) IV estimates using all plan and historical route instruments				
Miles to nearest freeway	1.161[c]	0.792[c]	0.579	0.191
	(0.258)	(0.205)	(0.367)	(0.176)
Kleibergen-Paap LM test (p)	0.000	0.001	0.003	0.046
Cragg-Donald Wald stat (F)	90.2	78.2	51.7	115.3
Kleibergen-Paap Wald stat (F)	20.4	9.1	5.0	4.1
Hansen J test (p)	0.209	0.154	0.447	0.686

Each cell is an estimate from a separate fixed-effects instrumental-variables regression of the logarithm of the 1950–2010 change in consistent-tract population on distance to nearest highway in miles and controls as in Table 1, Panel (b). All regressions include metropolitan area fixed effects. Estimated standard errors, robust to heteroskedasticity and clustering on metropolitan area, are in parentheses. [a]—$p < 0.10$, [b]—$p < 0.05$, [c]—$p < 0.01$.

Table 2 shows instrumental variables estimates. Panel (a) uses neighborhood distance to the nearest 1947 plan routes and shortest-path routes between 1947 plan cities as instruments for miles to nearest freeway. Panel (b) uses neighborhood distance to the nearest 1898 rail route and pre-1890 exploration route as instruments. Panel (c) uses all four instruments together. The IV estimates reveal qualitatitively similar patterns compared with the WLS estimates. In particular, the negative freeway effects (positive coefficients) estimated for city centers attenuate with distance to the CBD. The IV estimates are larger than those obtained from the OLS exercise, especially for the subsamples of neighborhoods closest to the city center. The inflation of the IV estimates

[6]One potential concern regarding the validity of this instrument is that topography or railroads might have persistent amenity value. Thus, the tests of overidentifying restrictions are of interest.

suggests that the causal effect of freeways is larger (more negative) than what simple growth rates suggest. In other words, highways were generally allocated to neighborhoods that had high growth potential. Historical and statistical evidence suggest that urban highways, particularly in city centers, were actually built along previously less-developed and less-dense "corridors" left behind by previous radial development patterns. (We review this evidence in section 5.) In sum, the instrumental variables estimates suggest that central-city freeways influenced by planned or historical routes caused especially large neighborhood population losses, compared with the average central neighborhood allocated a freeway.

Instrumentation is fairly strong. To test for underidentification, we report p-values for the Kleibergen-Paap (2006) LM test. The null hypothesis that the equation is underidentified is strongly rejected for every specification. To test for weak instruments, we report the Wald statistics of Cragg-Donald (1993) and Kleibergen-Paap (2006), the latter which is robust to non-i.i.d. errors (in particular, clustering on metropolitan area). These statistics suggest that weak instruments are not a major concern, especially for the two subsamples within 5 miles of city centers. For peripheral neighborhoods beyond 5 miles from the CBD, the cluster-robust F-statistic relatively small. The already-large standard errors and confidence intervals that substantially overlap the WLS estimates underline the extent to which weak instruments may pose a challenge to inference about the causal effects of freeways in suburban locations. Finally, we also test the overidentifying restrictions by reporting p-valus from a Hansen (1982) test. Overall, we fail to reject the null hypothesis that the full set of instruments is valid.

4.3 Robustness

To illustrate the robustness of the results so far, Figure 4 reports coefficient estimates for other specifications. The baseline IV results reported in Table 2, panel (c) are shown in red on the left side of each panel. (The circle marks the point estimate and the lines indicate the 95 percent confidence interval.) The second line in each panel, and the first blue line, indicate estimates from a specification that also includes 1950 tract characteristics as controls—the black share of the population, average educational attainment, average household income, and average housing values and rents. The third line excludes New York and Los Angeles from the sample. The fourth line performs unweighted regressions. Across specifications, the coefficient estimates are precise and stable. They also replicate the important pattern of the main result: Strong negative freeway effects (positive estimates) close to city centers that attenuate with distance to the CBD.

Up to this point, we have only considered the access benefits of highways for commuting to the CBD. However, this same analysis could apply to other regional level destinations. The fifth line in each panel of Figure **??**(a) reports coefficient estimates where the sample of neighborhoods is conditioned on distance to the nearest coastline instead of distance to the city center.[7] Coastlines potentially provide production benefits (i.e., job centers tend to be coastal) and consumption ben-

[7] For this analysis we include Great Lakes in addition to oceans, and we drop metropolitan areas that are not near a coastline.

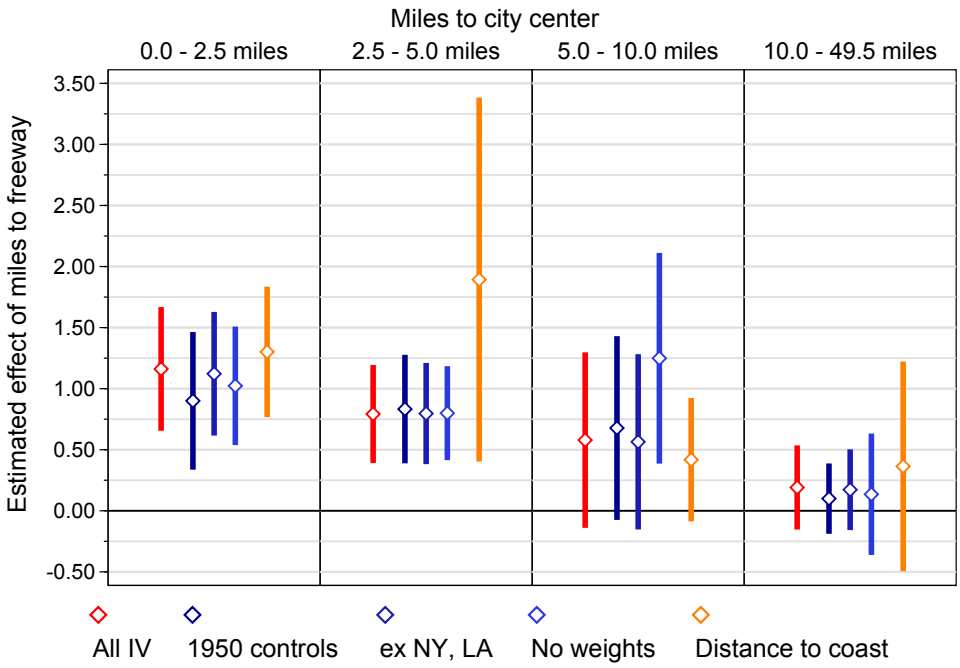


Figure 4: Robustness of freeway effects on population

Estimates from separate instrumental-variables fixed-effects regressions of the logarithm of the 1950–2010 change in consistent-tract population on distance to nearest highway in miles. All regressions include metropolitan area fixed effects. Lines extending from point estimates show 95 percent confidence intervals, robust to heteroskedasticity and clustering on metropolitan area.

efits (views, beaches, and moderate temperatures are all complements to recreational activities). Thus, coastlines tend to be desirable regional destinations. Whether they provide production or consumption benefits, they may on a regional scale—thus, we expect that locations far from the coast benefit more from freeway access, while locations near the coast would mostly experience only the freeway disamenity. The estimates in this case are very similar to those using distance to the CBD. Freeways have large negative effects for neighborhoods close to coastlines, and these negative effects attenuate with distance to the coast. Overall, this provides additional insight in the cost and benefits of highway construction in urban areas.

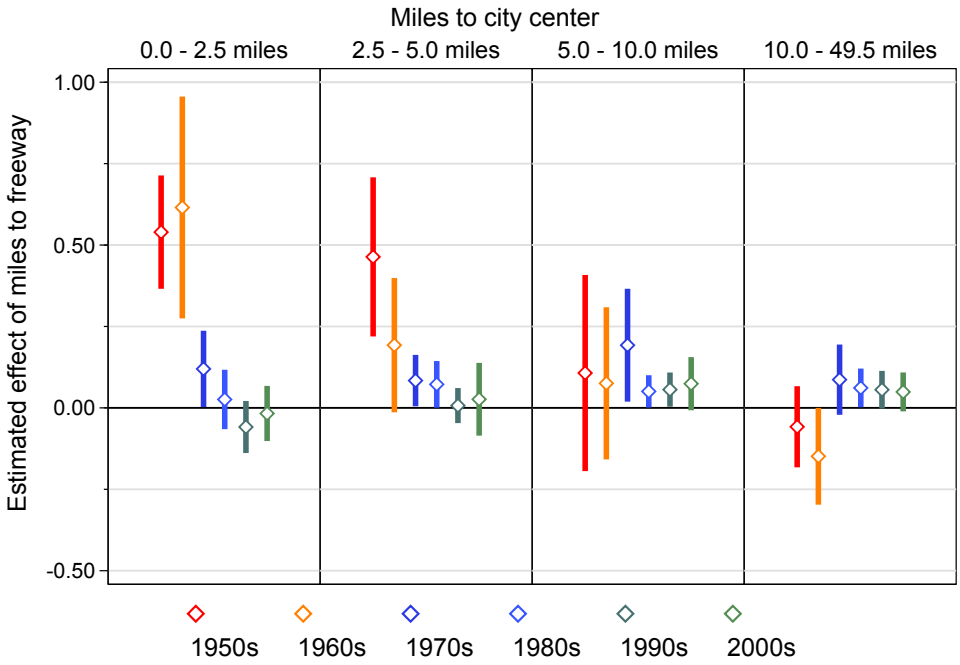


Figure 5: Freeway effects on population largest in the 1950s and 1960s

Estimates from separate instrumental-variables fixed-effects regressions of the logarithm of the 10-year change in consistent-tract population on distance to nearest highway in miles. All regressions include metropolitan area fixed effects. Lines extending from point estimates show 95 percent confidence intervals, robust to heteroskedasticity and clustering on metropolitan area.

Next, we investigate the change in neighborhood population over time, accounting for the timing of interstate construction. In this exercise we regress change in population in each decade on distance to the CBD and distance to the highway on only highways that were currently completed. We use the same IV strategy as before. Note that these estimates differ in three ways compared with those reported earlier. One, we use the PR-511 database to measure the year each interstate segment was first open to traffic. Two, because the PR-511 database only includes designated Interstate highways, we cannot measure the date when non-Interstate limited-access freeways were first open to traffic. Thus, neighborhood freeway proximity is conditioned on distance to the nearest *Interstate* highway in these regressions. Three, these are 10-year changes in population, so

the magnitudes of the coefficients are expected to be smaller.

Figure 5 shows these estimates. The negative effects of freeway construction in central cities were most pronounced between 1950 and 1970. (About three-quarters of the Interstate highway network was completed before 1970.) After 1970, the effects are more modest, which corresponds with the decline in freeway construction.

4.4 Sorting

Next, we consider the effects of freeways on the spatial sorting of different types of households. We regress the change in the logarithm of average household income between 1950 and 2010 on neighborhood distance to the nearest freeway. Recall that the theoretical predictions for sorting effects are ambiguous and depend on the source(s) of household heterogeneity, as well as the form of the commuting technology. This ambiguity is reflected in the estimationg results shown in Figure 6, which echo the results using population growth but are somewhat weaker.

Nonetheless, the results suggest that freeway construction caused several changes in the sorting patterns of different income groups. Higher income groups sorted away from freeways, and that this effect was larger in city centers compared with the suburbs. Again, these results are consistent with several sources of heterogeneity, and thus we cannot definitively attribute these results to specific differences between income groups. Recall from the previous discussion and Equation **??** that there are three important sources of heterogeneity: (i) differences in expenditure shares, (ii) differences in amenity valuation, and (iii) differences in the effects of transportation costs. The changes observed would be consistent with decreased expenditure shares on housing for higher income groups (i.e. $1 - \beta_H < 1 - \beta_L$). As transportation costs decline, higher income groups benefit relatively more from moving to areas farther from the CBD. In addition, particularly near the CBD, this would lead to sorting of high income households away from the freeway. In suburban areas, the sorting with respect to proximity would be ambiguous, and the coefficients on the interaction term are consistent with this explanation.

However, the empirical results would also be consistent with other sources of heterogeneity. If amenity valuation changes by income, ($\gamma_H > \gamma_L$), then this would result in sorting away from freeways everywhere. In addition, differences in relative benefits of highways through the net wage function $\ln w_i(x; d_F, v_F)$ itself, could lead to sorting of high income residents away from the CBD. This would happen in the presence of fixed or per mile commuting costs, that are not proportional to income.

While we cannot pin down the structural source of changes in sorting patterns, the results do suggest that freeway construction has a relatively greater effect on the bid rent of high income groups both in terms of increased benefits of access and in decreased amenities near freeways. More generally, this result is consistent with the idea that high income workers will outbid low income worker for the "best" neighborhoods in terms of access and amenities, which aligns with the mechanisms and analysis by Lee and Lin (2017).

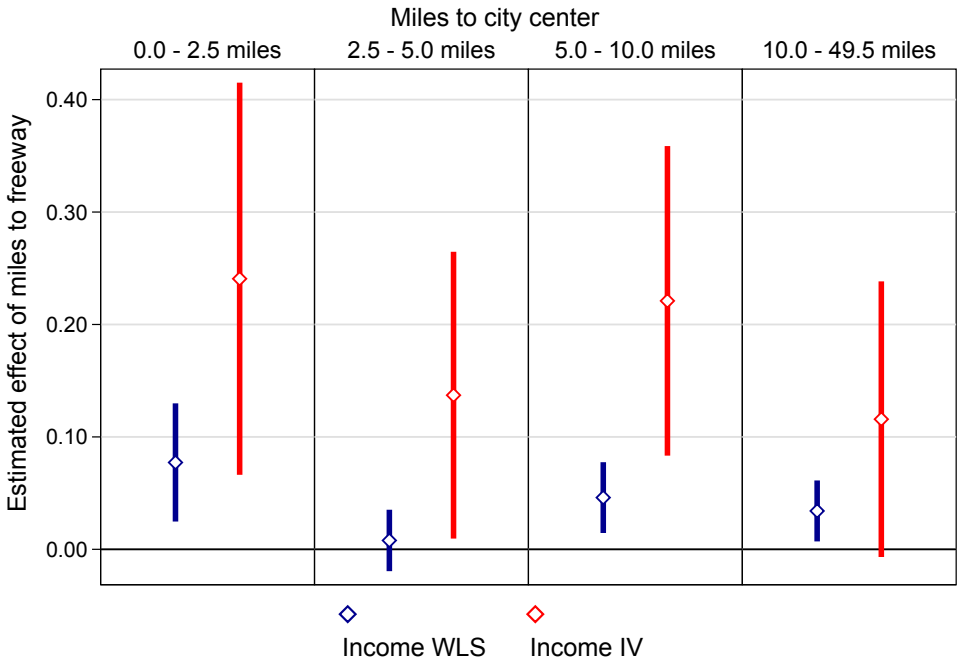


Figure 6: Robustness of estimated effect of freeway proximity on population change

Each cell is an estimate from a separate fixed-effects regressions of the logarithm of the 1950–2010 change in consistent-tract average household income on distance to nearest highway in miles. All regressions include metropolitan area fixed effects. Lines extending from point estimates show 95 percent confidence intervals, robust to heteroskedasticity and clustering on metropolitan area.

4.5 Job growth

So far, we have inferred freeway disamenities from population and income declines near central-city freeways. While this conclusion is consistent with our theory, the simple model abstracts from firm location decisions. If firms endogenously choose neighborhoods, then population declines may also reflect increasing bid-rent by firms for land near freeways. (The richer version of the model presented in section **??** does allow for endogenous firm location.) For example, the growth of large suburban shopping centers near highways ("edge cities") seems to reflect improved productivity rather than decreased amenity (Garreau, 1991). In particular, it would challenge our interpretation of freeway disamenities if population declines near central-city freeways were caused not be declines in amenity value but by increases in firm demand.

A challenge for evaluating the role of firms and productivity growth is obtaining suitable data. In this section, we estimate the effects of freeway proximity on neighborhood job growth.[8] We use

[8] Reliable measures of land value are difficult to obtain for a large universe of small geographic units in the 1950s. Housing prices are available in the Census of Population and Housing, but unobserved heterogeneity in housing quality presents another challenge for inference. As detailed later, standard modern measures of employment, which would shed light on firm location decisions, such as the Economic Census or covered Unemployment Insurance records, suffer from poor industry and spatial coverage in the early 1950s.

data constructed from historical household travel surveys to identify the location of jobs in the 1950s. These household travel surveys record trip characteristics for a reference day or period.[9] They record trip origins and destinations, often at precise latitudes and longitudes, the purpose of each trip, the mode of travel, and the time spent travelling. By combining information on trip *destinations* with trip with the stated *purpose* of going to work, we are able to measure the location of jobs. Travel surveys have their origin in the early 20th century, as planning for interregional highways began (Levinson and Zofka, 2006). The Bureau of Public Roads (now the FHWA), in coordination with states, metropolitan planning organizations, and municipal government, developed the modern survey methods still in use following modest funding from the Highway Act of 1944. Schmidt and Campbell (1956) note that at least 45 cities or metropolitan areas conducted household travel surveys between 1946 and 1956. Unfortunately, most of these surveys that predate the Interstate highway construction have apparently been lost.

For this study, we digitized data from surveys conducted in the Detroit metropolitan area in 1953 and the Chicago metropolitan area in 1956. These surveys are notable for being methodologically advanced—the Detroit study "put together all the elements of an urban transportation study for the first time" (Weiner 1999, p. 26). The Detroit and Chicago surveys used large stratified samples of about 3 and 4 percent of the metropolitan population, respectively. They are structured similarly compared with modern travel surveys, they record both work and non-work trips, and they provide detailed geographical information. We re-discovered the Detroit trip-level microdata; the last significant use of these microdata appear to have been by Kain (1968) in his pioneering study of segregation and spatial mismatch. Unfortunately, the household- and trip-level microdata from the Chicago survey appear to be lost; a representative of the still-extant metropolitan planning organization reponsible for the 1956 survey reported that the original records were discarded several years ago during an office relocation. Instead, we digitize summary information on employment by sector and "zone" (a small geographic unit) obtained from several articles published in the study's own periodical, *CATS Research News*. We combine this information with published land-use survey maps conducted at the same time by the metropolitan planning organization to assign employment by sector and zone to census tracts. For Detroit, we aggregate jobs to census tracts using the survey's latitude and longitude for trips to work and the sample weights.

Estimates of jobs from these travel surveys tend to match well aggregates reported by other sources. In 1956 Chicago, we are able to assign to census tracts 1,212 thousand jobs. This compares favorably to other contemporary estimates. The overall 1956 travel survey reported 1,500 thousand person-trips to work (about 300 thousand jobs were not separately reported by zone). The 1954 Census of Business (now the Economic Census) reported 1,082 thousand jobs in the city of Chicago (smaller than our sample area) and 1,324 thousand jobs in Cook and DuPage counties (larger than our sample area)[10]. Unlike the travel survey, the Census of Business notably lacked coverage of

[9] They are also referred to as "trip diary" or "origin-destination" surveys. Modern versions of these surveys include the National Household Travel Surveys in 2001 and 2009 (previously the National Personal Transportation Surveys of 1969, 1977, 1983, 1990, and 1995) and the Census Transportation Planning Products in 1990 and 2000.

[10] The 1956 Chicago travel survey sampled an area consisting of nearly all of Cook County, the eastern half of

employment in construction, transportation, communications, utilities, finance, and many services. Finally, the 1950 Census of Population reported 2,036 thousand jobs reported by residents of Cook and DuPage counties.

In 1953 Detroit, we are able to assign 983 thousand jobs to census tracts using sampling weights. This compares favorably to 1954 Census of Business estimates of 681 thousand (Wayne county, comparable our sample area) to 816 thousand (Detroit metropolitan area, larger than our sample area)[11]. The 1950 Census of Population also reported 983 thousand jobs reported by residents of Wayne county.

For modern estimates of jobs by census tract, we use the Census Transportation Planning Product from 2000 for Chicago and the 1994 Detroit travel survey, whose structure followed very closely the original 1953 survey.

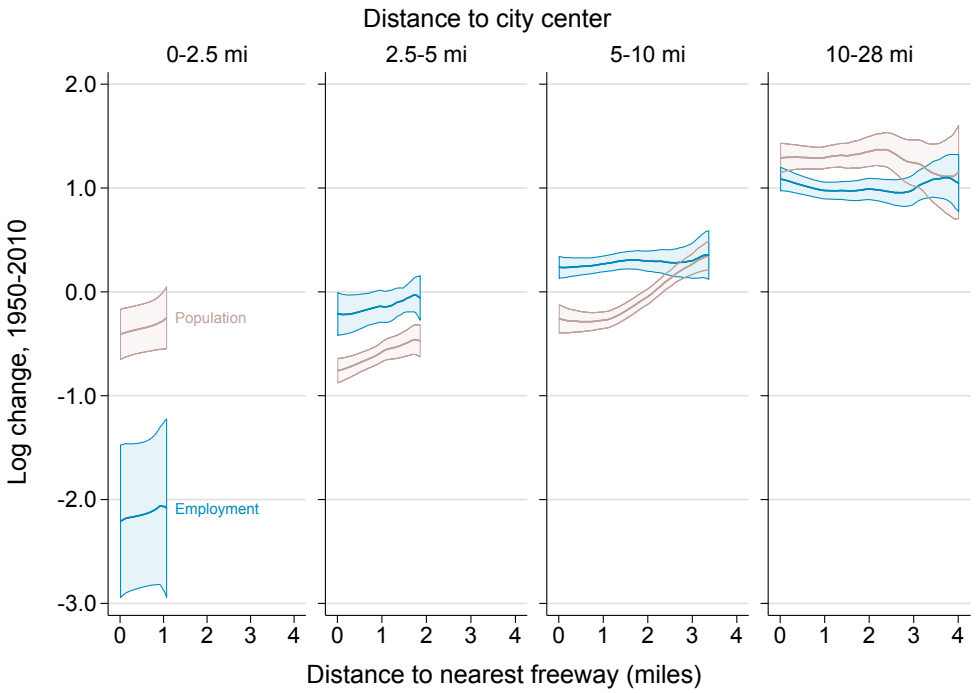


Figure 7: Changes in population and employment in Chicago

Lines show kernel-weighted local polynomial smooths of the 1950–2010 change in the natural logarithm of consistent-boundary tract population or the 1956–2000 change in the natural logarithm of consistent-boundary tract employment for neighborhoods in the Chicago metropolitan area. Smooths use Epanechnikov kernel with bandwidth 0.4 and local-mean smoothing. Shaded areas indicate 95 percent confidence intervals.

Figure 7 summarizes patterns of long-run population and job growth for census tracts in the Chicago metropolitan area. Each panel represents subsamples conditioned on distance to the city center. Each line shows kernel-weighted local polynomial smooths of the change in the natural logarithm of tract population or employment. Several features of Figure **??** are worth noting. One, the

DuPage county, and very small portions of Will and Lake (IL) counties.

[11] The 1953 Detroit travel survey sampled most of Wayne county and portions of Oakland and Macomb counties.

relationship between population growth and proximity to freeways and the city center corresponds to the patterns observed in Figure 1 and is similar to the pattern observed across all U.S. cities seen in Figure 2. Population declined in central Chicago, both in absolute terms and compared with the periphery. Further, population declines near freeways are most pronounced at the city center. Two, employment declined in central Chicago up to 5 miles from the city center. Three, among central neighborhoods, those assigned new freeways saw larger employment declines compared with downtown neighborhoods farther from freeways. Four, among neighborhoods more than 10 miles from the city center, those assigned new freeways saw larger employment gains compared with outlying neighborhoods farther from freeways. Interestingly, tracts that lost population also tended to lose jobs. Population and job growth are positively correlated, with correlation coefficients of 0.40 and 0.41 in Chicago and Detroit, respectively. In sum, Figure 7 provides evidence that the geography of jobs evolved similarly compared with the geography of population. The evidence is less consistent with the hypothesis that increases in firm demand caused by freeways displaced households in central areas.

Table 3 shows results of regressions of long-run changes in population and employment in freeway proximity for three categories of tracts in Chicago and Detroit by distance to the city center. (We aggregate the downtown tracts within 5 miles into one category because of small sample sizes.) Panels (a) and (b) replicate baseline regressions presented in Tables 1(b) and 2(c) and show similar results. Freeways are associated with population declines downtown and population increases in peripheral area. The IV results support a causal interpretation, though in Detroit, especially for the downtown sample, instrumentation is weak and confidence intervals are wide. Panel (c) shows estimates from a least-squares regression of the 1956–2000 (Chicago) and 1953–1994 (Detroit) change in tract employment on miles to the nearest freeway and controls as in Tables 1(b). In downtown Chicago, jobs increased more farther from freeways, while in suburban Chicago, jobs increased more close to freeways. These coefficients are consistent with the patterns seen in Figure 7, although they are not precisely estimated. The Detroit results are mixed. The least-squares estimates suggest that the employment growth premium was higher near downtown freeways compared with suburban freeways, but the estimates are imprecise.

Overall, the results from Chicago and Detroit suggest that freeways affected the geography of population and jobs in roughly the same way. Downtown neighbohroods near freeways had slower population growth, consistent with results across all sample cities presented earlier. But downtown freeway neighborhoods did not have significantly faster employment growth in Chicago and Detroit. While point estimates are imprecise, they suggest that instead, downtown freeways caused both population and employment to decline. Meanwhile, peripheral neighborhoods near freeways experienced both faster population and job growth compared with peripheral neighborhoods farther from freeways. Taken together, these results suggest that changes in the geography of jobs are unlikely to account for declines in population near downtown freeways.

	Chicago			Detroit		
	(1)	(2)	(3)	(4)	(5)	(6)
	Distance to city center:			*Distance to city center:*		
	0–5 miles	5–10 miles	10–28 miles	0–5 miles	5–10 miles	10–21 miles
(a) Population — OLS						
Miles to freeway	0.403^{c}	0.140^{c}	-0.114^{c}	0.078	0.073	-0.049
	(0.092)	(0.034)	(0.040)	(0.151)	(0.046)	(0.057)
Neighborhoods	263	460	648	105	218	207
(b) Population — IV						
Miles to freeway	0.220^{a}	0.332^{c}	-0.915^{c}	6.408	-0.010	-0.648^{c}
	(0.113)	(0.057)	(0.196)	(8.316)	(0.137)	(0.206)
K-P LM test (p)	0.000	0.000	0.000	0.709	0.000	0.000
C-D Wald (F)	68.3	59.4	9.5	0.2	16.7	13.1
K-P Wald (F)	73.7	69.8	8.5	0.3	17.5	11.0
Hansen J test (p)	0.000	0.000	0.000	0.859	0.660	0.097
(c) Employment — OLS						
Miles to freeway	0.112	-0.035	-0.080^{b}	-0.305	-0.228	-0.050
	(0.210)	(0.036)	(0.033)	(0.603)	(0.201)	(0.175)
(d) Employment — IV						
Miles to freeway	0.245	-0.179^{c}	0.175	0.992	-0.031	0.295
	(0.292)	(0.058)	(0.156)	(1.530)	(0.340)	(0.354)
K-P LM test (p)	0.000	0.000	0.000	0.138	0.000	0.000
C-D Wald (F)	68.3	59.4	9.5	4.7	11.5	6.6
K-P Wald (F)	73.7	69.8	8.5	2.2	9.4	6.0
Hansen J test (p)	0.000	0.000	0.007	0.015	0.670	0.000

Table 3: Effect of freeways on population and employment in Detroit

Each panel–column reports a separate regression. Estimated standard errors, robust to heteroskedasticity, are in parentheses. ^{a}—$p < 0.10$, ^{b}—$p < 0.05$, ^{c}—$p < 0.01$. Regressions reported in panel include controls for neighborhood proximity to nearest park, lake, seaport, river, coastline, and city center in miles, and four categories indicating average neighborhood slope.

4.6 Travel flows

A second piece of evidence from the travel survey data highlights the *barrier effects* of freeways—that is, reduced accessibility and increased travel costs to destinations on the opposite side of a freeway. Actual barriers, such as the Berlin Wall, can block spatial spillovers (Ahfeldt et al., 2015; Redding and Sturm, 2008). Less is known about the effects of *pseudo*-barriers such as rail lines or highways. Ananat (2011) uses the geography of historical rail lines as an instrument for variation in racial segregation across cities, noting that railroads tend to delineate neighborhoods, and historically they offered white households a "retreat" from the influx of Black households during the Great Migration. Quoting Schelling (1963), Ananat suggests the role of railroads in the coordination of expectations among households, realtors, and others in maintaining racially segregated neighborhoods. Alternatively, by severing the network of streets, railroads also increase the cost of cross-neighborhood interaction. Our contribution is to provide the first evidence of barrier effects from freeways using travel time and flow data.[12]

We analyze trip flows using the Detroit survey from 1953 and the follow-up survey conducted in 1994. A database of trips records the origin and destination latitudes and longitudes. We then measure the distance of the crow-flies route between these coordinates. To provide evidence on the barrier effects of highways, we compare travel flows between pairs of census tracts in 1953 and 1994.

Figure 8 shows the emprical cumulative distribution of trip length in miles in 1953 and 1994. Consistent with a decline in transportation costs, the average trip in the Detroit metropolitan area lengthend from 3.7 to 5.1 miles. However, a large share of trips continue to be made at short distances: the median trip increased only from 2.6 to 2.7 miles. (Note that both work and non-work trips are included in these figures.) Trips by automobile increased from 82 percent in 1953 to 88 percent in 1994. Trips to work (one-way) accounted for 24 percent of trips in 1953 and 20 percent of trips in 1994.[13]

To analyze the effects of freeways on travel behavior, consider the following "structural gravity" equation that describes travel flows π_{jk} from census tract j to tract k in period $t \in \{1953, 1994\}$ (Head and Mayer, 2014). This equation follows from the commuting probabilities in the structural model presented in section **??**, except that constant terms are subsumed into fixed effects.

$$\pi_{jkt} = \rho_{jt}\varsigma_{kt}\upsilon_{jk}e^{\nu\tau_{jkt}} \tag{2}$$

where origin-year (ρ_{jt}) and destination-year fixed effects (ς_{kt}) capture neighborhood-specific characteristics such as prices, wages, amenity and productivity in each year, origin-destination fixed effects (υ_{jk}) capture pair-specific characteristics that are time invariant, such as pair distance and fixed transportation infrastructure, travel costs are $d_{jk} = e^{\kappa\tau_{jkt}}$, and τ_{jkt} is the cost of travelling

[12] A large literature in ecology examines the effects of roads on the movement of wildlife (e.g., Forman and Alexander, 1998).

[13] While the 1953 survey records purpose at both origin and destination, the 1994 survey only records purpose at destination.

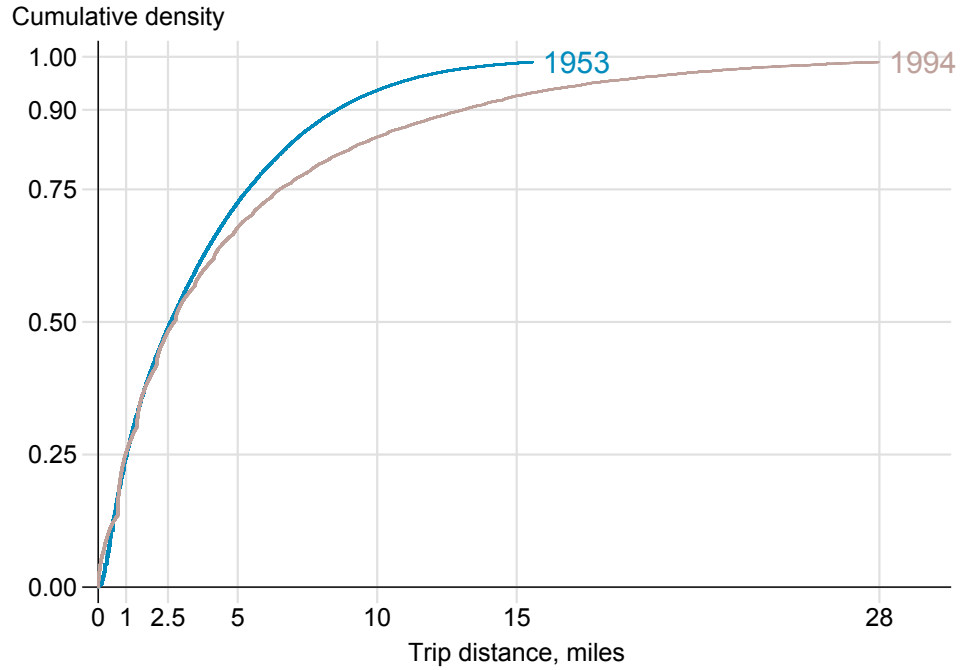


Figure 8: Cumulative distribution of trip length in 1953 and 1994

This plot shows cumulative densities of trip lengths in 1953 and 1994 using sample weights. Densities are truncated at the 99th percentile of trips.

from tract j to tract k in year t. The parameter $\nu = -\epsilon\kappa$ is the semi-elasticity of commuting flows with respect to travel costs.

We'd like to know how the construction of Interstate freeways affected travel costs τ_{jkt} and travel volumes π_{jkt}. To do so, we assume that travel costs are a function of distance and the freeway network. The effects of distance and other fixed transportation infrastructure would be absorbed in tract-pair fixed effects, but the effects of newly-constructed freeways may vary by tract-pair distance. This could be because of shifts in mode choice from walking to driving at longer distances, or it could be because the marginal cost of detours forced by fewer cross-freeway arterials is higher at shorter distances. At long distances, the benefits from increased travel speeds likely exceeds any local disruptions to the surface street network.

We assume that $\tau_{jkt} = v_1 1(I_{jkt}) 1(D_{jk} < \Delta) + v_2 1(I_{jkt}) 1(D_{jk} \geq \Delta)$, where $1(I_{jkt})$ is a dummy variable indicating whether a freeway constructed between 1953 and 1994 crosses the shortest-distance path betwen tracts j and k, and $1(D_{jk} < \Delta)$ is a dummy variable indicating whether the shortest distance path between tracts j and k is within a threshhold distance Δ. We use the PR-511 data to identify which freeway segments opened to traffic between 1953 and 1994. We perform separate estimations varying the distance threshhold Δ to flexibly account for freeway effects that vary by trip distance.

One could estimate equation (2) by taking logs and assuming an additive i.i.d. error, but this is

known to lead to biased estimates (Santos Silva and Tenreyro, 2006). In addition, with 855 tracts in 1950, we have over 731 thousand tract pairs. Given our relatively small sample size (about 250 and 30 thousand sample trips in 1953 and 1994, respectively), a large share of tract pairs have zero observed flows. While two-thirds of tract pairs less than a mile apart have nonzero observed flows, just 1.5 percent of pairs more than 10 miles apart have observed travel flows. (Overall, 6.2 percent of tract pairs have nonzero observed flows.) Thus, using the logarithm transformation is problematic. Instead, we assume a multiplicative error η_{jkt} with $E[\eta_{jkt}|\alpha_t, \rho_{jt}, \varsigma_{kt}, \upsilon_{jk}, \tau_{jkt}] = 1$ and estimate equation 2 using the Poisson psuedo-maximum likelihood (PPML) estimator. Santos Silva and Tenreyro (2006) show that PPML produces consistent estimates and performs well in the presence of zeros.[14]

The origin-year and destination-year fixed effects absorb changes in the desirability of tracts as origins or destinations that may be caused by the construction of freeways. They also capture year-specific factors that affect all flows. Thus, identification comes from variation *within* origin, *within* destination, and *over time* within origin-destination pair.

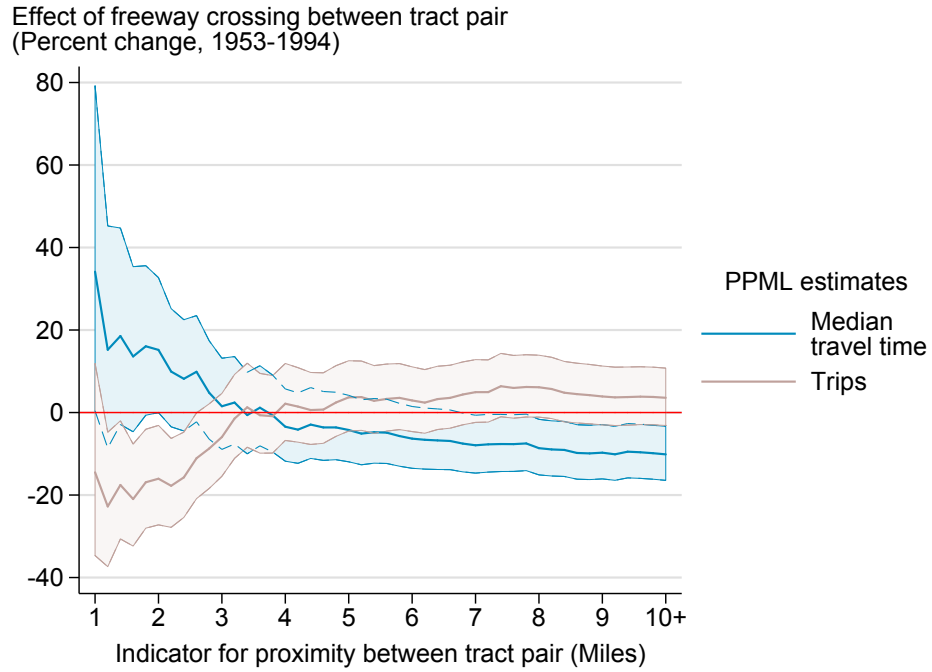


Figure 9: Fewer trips across freeways at short distances and more trips at long distances

Figure 9 shows in brown PPML estimates of $e^{\widehat{\nu v_1}}$, the semi-elasticity of travel flows with respect to freeways at distances of less than a threshhold distance Δ. Shaded areas show 95 percent confidence intervals using standard errors clustered on tract pairs.[15] The estimated parameter

[14] Head and Mayer (2014) show additional Monte-Carlo evidence showing good performance of the PPML estimator in the presence of "statistical" zeros.

[15] We use the estimator by Larch et al. (2017).

combines both the change in travel costs after the tract pair is "treated" with a bisecting freeway (v_1) with the response of trip demand (ν). Each point connected by the brown line shows a separate estimation, varying the threshhold distance Δ. The estimates are exponentiated, so the values can be interpreted as percentage changes. Thus, for trips of 2 mile or less, freeway construction is associated with a nearly 20 percent decline in the volume of trips between 1953 and 1994. Only for trips longer than 4 miles are freeways associated with increases in travel volumes. Over larger distances, freeways that bisect tract pairs can be thought of as offering a faster route compared with extant surface streets.

We also estimate the effect of freeways on the median reported travel time between tract pairs in a similar framework, absorbing origin-time, destination-time, and origin-destination fixed effects. These estimates are shown varying by trip distance in blue. The point estimates suggest that at distances up to 2 miles, trip times increase nearly 20 percent when tract pairs are bisected by freeways.

Freeway routes may have been selected to divide neighborhood pairs where travel flows were expected to fall. If this was the case, then the estimates in Figure 9 cannot be interpreted as causal effects. However, to the extent that route choice was based on time-invariant factors, those will be accounted for the the tract pair fixed effects υ_{jk}. In future work, we plan to use planned and historical routes to instrument for actual freeways.

5 The freeway revolts and the changing allocation of freeways

In this section, we explore the consequences of the freeway revolts for the allocation of freeways in U.S. cities. We discuss the two most relevant stages in the history of U.S. public infrastructure investment identified by Altshuler and Luberoff (2003). They first describe the "mega-project" era (1950–late 1960s) as characterized by massive federal aid, public consensus, and control by concentrated federal and state authority. This era spanned the period of major highway construction in the U.S., but as for public consensus and concentrated power over the Interstate program, probably peaked around the passage of the Federal-Aid Highway Act of 1956. Second, the era of the revolts (middle 1960s–early 1970s, called the "transitional" era by Altshuler and Luberoff) was characterized by grassroots protests over the impacts of freeways on neighborhoods and the environment. During the 1960s, federal policy gradually ceded more control to local interests. As a result, (some) neighborhood groups were able to significantly alter the routing of freeways. In some cases, they were able to block freeway projects entirely. According to DiMento and Ellis (2013), by 1967, federal and state policy had decisively swung in favor of the revolts.

5.1 Highway planning before 1955

Congress began considering what would become the Interstate Highway System in the 1910s and 1920s. In this period, high-speed, limited-access roads were planned and financed by state and local agencies dominated by highway engineers. (The bulk of federal funding would not come until

the 1956 highway act.) These builders did not anticipate negative amenity effects, nor did other planners and policy makers. Concept drawings by Le Corbusier and others in the 1920s and 1930s showed "broad highways penetrat[ing] central cities, slicing through phalanxes of skyscrapers" (DiMento and Ellis, 2013, p. 17). A 1924 plan for Detroit showed superhighways with a "'parkway' ambience [...] reinforced by groups of pedestrians ambling along only a few feet from the freeway, as though it were a Parisian boulevard" (p. 19). Through the 1930s, planners' views of effects of automobiles were still immature. "[T]he meaning of the automobile—and of parkways—was quite different [...] from its later incarnations. [...] Even Lewis Mumford [...] viewed the automobile as a beneficent liberator of urban dwellers from the cramped confines of the industrial city" (p. 38).

Urban freeway planning in the 1940s and 1950s was still dominated by highway engineers at state highway departments and the federal Bureau of Public Roads (BPR), whose experience was almost entirely in building out the rural sections of the national highway network under the provisions of the Federal-Aid Highway Act of 1944. Rural highway building was less concerned with negative externalities and displacing existing factors. Instead, speed and capacity were the guiding concerns. "Between 1946 and 1956 [...] [i]nitial planning was begun on the interstate system, with state highway departments taking the lead and emphasizing traffic-carrying efficiency [...]" (p. 100). Few city officials (not even considering local residents) were involved in planning. "The planning and design professions stood outside the highway planning community [...] State highway departments consolidated their hold on the urban freeway planning process, eclipsing local planning and public works officials" (p. 100).

5.2 The mega-project era and the "Yellow Book" plan of 1955

The mid-1950s marked a turning point in the development of the Interstate Highway System. In 1947, the BPR had mapped about 90 percent of National System of Interstate Highways authorized (but incompletely funded) by Congress in the Federal-Aid Highway Act of 1944. This map showed rural routes that terminated outside metropolitan areas. In 1955, the remaining (urban) mileage was designated by the BPR in a series of maps contained in the *General Location of National System of Interstate Highways Including All Additional Routes at Urban Areas Designated in September 1955*, known as the "Yellow Book." Unlike the 1947 plan, which described only routes *between* cities, the Yellow Book described the general routing of highways *within* each of 100 metropolitan areas. We digitized the 1955 Yellow Book maps for this project to use as a baseline to analyze the changing allocation of freeways. These routes were determined with the cooperation of State highway departments according to several criteria. Routes were favored that (1) penetrated the downtown core or (2) circumvented central cities via beltway; (3) used undeveloped land; (4) linked to other modes such as rail stations and ports; (5) followed forecasted demand and (6) topography and physical feature such as rivers; and (7) were compatible with existing land uses and (8) national defense ("Criteria for Selection of Interstate System Routes," testimony by Commissioner of Public Roads C.D. Curtiss, April 15, 1955, in Weingroff, 2015). (As discussed later, these selection criteria

are useful for understanding the selection effects driving differences between the least-squares and instrumental-variables results on population growth.)

The Federal-Aid Highway Act of 1956 authorized the 41,000 mile Interstate system to be built over 13 years (Weingroff, 1996). Importantly, the Act provided for 90 percent federal funding, lowering the last major barrier for mass construction of urban freeways. "The mass production of urban interstates would soon be under way [...] Between 1956 and 1970, urban freeway form concepts [...] became blueprints for actual construction" (DiMento and Ellis, p. 102). State highway departments, "believ[ing] they had to finish the entire 41,000 miles within the 13-year funding framework" (Weingroff, 2016), raced to complete their segments. State highway departments varied in their initial planning and construction. The AAHSO (1965) noted that

> Not all Interstate routes were starting from the same point, in 1956. Some sections, indeed, were already completed, although mostly these were toll roads. Some others were in varied stages of development: a 2-lane highway needed expansion to 4 lanes; an expressway lacking full control of access or needing additional grade separations or lanes [...] Not all States were starting from the same point in 1956, either, for a variety of reasons. A "shelf" of project plans was available in some States but not others. Some State highway departments were able to staff up to a job rapidly while others took mch longer; many had previously done little or no right-of-way acquisition on their own; some had never before designed or built freeways on a large scale.

An important feature of this period is that, as of 1955, highway planners did not anticipate the breadth or intensity of community resistance to urban freeway plans. "[N]o one anticipated the urban battles ahead so no one thought 'I better build my urban segments right away before anyone starts fighting them.' Officials simply made choices about the priority of each segment for construction based on whatever factors they considered important" (Weingroff, 2016).

5.3 The spread of freeway revolts after 1955

In 1955, residents in the path of the Western Freeway in San Francisco organized to fight the proposed route (Dimento and Ellis, p. 137). Protests, later termed "freeway revolts," continued to spread to a large number of cities in the 1950s and 1960s. Although the most famous are in San Francisco and lower Manhattan (e.g., the LOMEX proposal that set Jane Jacobs against Robert Moses), Wikipedia notes over 200 controversial freeway proposals that experienced community protests, across 50 cities. Lowell K. Bridwell, an early federal administrator who was sympathetic to revolts, noted highway planners faced social and environmental "problems of a serious nature in at least 25 cities" in March 1968 (Mohl, 2008, p. 202). Of course, the widespread freeway revolts are *prima facie* evidence of the negative amenity effects of freeways.

In response to spreading freeway revolts, the policy and practice of highway planning began to change. According to Mohl (2004):

> The timing, progress, and outcome of the emerging freeway revolt differed from city to city ... [I]n cities where the highway builders moved quickly in the late 1950s to build the urban interstates, the inner beltways and radials, opposition never materialized or was weakly expressed. [...] Where freeway construction was delayed into the 1960s, affected neighborhoods, institutions, and businesses had time to organize against the highwaymen. In some cases, freeway fighters successfully forced the adoption of alternative routes, and they even shut down some specific interstate projects permanently (p. 675)

In addition, subsequent highway bills responded to the freeway revolts by making it more difficult for highway planners to override community opposition. For example, the 1958 highway act first required State highway planners to hold public hearings and consider economic effects in advance of construction. The 1962 highway act further required that highway projects be "carried out cooperatively" with local communities (DiMento and Ellis, 2013). Highway legislation in 1966 and 1968 created new environmental and historic-preservation hurdles for new highway construction. In addition, highways were now subject to the Department of Transportation, established in 1966 and opened in 1967. Its first Secretary, Alan S. Boyd, was sympathetic "to the public clamor over the damaging impact of interstates in urban neighborhoods" (Mohl 2004, p. 681). By 1967, "The freeway debates and protests of the late 1960s begin to erode formerly uncritical acceptance of urban freeways." (DiMento and Ellis, 2013, p. 140). "Within a year of taking office at the DOT [in 1967], [Secretary of Transportation] Boyd had seemingly become the most effective national spokesman for the freeway revolt." (Mohl 2004, p. 681).

5.4 The changing allocation of freeways

Next, we show evidence from a wide section of cities that the freeway revolts and the increasing legislative requirements combined to change the allocation of freeways to neighborhoods over time. First, we show that for the Washington, D.C., metropolitan area, freeways that were programmed earlier tended to built according to plan, while several freeway segments that were programmed later were eventually re-routed or canceled entirely. Then, using the opening dates of Interstate segments drawn from the PR-511 database, we show that neighborhoods where new Interstates opened in the first few years following the 1956 Highway Act tended to share similar natural and predetermined characteristics compared with neighborhoods selected in the Yellow Book plan. However, beginning in the late 1950s through the 1960s, new Interstate segments increasingly diverged from the Yellow Book plan. These patterns are consistent with the historical evidence presented so far that freeway planners did not expect the breadth and intensity of subsequent freeway revolts circa 1955, and because of the growing freeway revolts, interstates that were bulit later were less likely to be completed along their initial planned routes. Instead, later Interstates tended to open in historically black and less-educated neighborhoods, consistent with the political economy channels emphasized by Glaeser and Ponzetto (2017).

5.4.1 Evidence from programming dates in Washington, D.C.

To provide some evidence on the evolution of freeway allocation, we examine highway programming in the Washington, D.C. metropolitan area. "Programming" refers to initial engineering and design work for a highway segment. To our knowledge there is no comprehensive study of freeway planning, programming and revolts across many states and cities. Getting information on planning dates for unbulit highways is especially difficult. However, there is pretty good information on highway planning from individual state and US DOT records, e.g., PR-511 data, for routes that were eventually built. In addition, for unbuilt highways, portions or stubs that *were* built may have program dates from the PR-511 records. These stubs' program dates can then be extrapolated to unbuilt segments. Also, there are many case studies of individual highway segments and cities on planning dates for segments that were eventually abandoned. (In the case of Washington, D.C., we rely on detailed histories on the web sites DCroads.net and Roads to the Future, as well as contemporary accounts in the Washington Post.)

We define a segment as a unique route number-county-intersecting route combination.[16] Figure 10 shows these divisions in the 1955 Yellow Book plan. It also shows the program dates, measured to the best of our ability. Programming dates are determined as follows. For segments of the Yellow Book plan that were eventually built and have valid PR-511 data, we use the latest date of right-of-way acquisition or PS&E development (plan, specification, and estimate) listed. For segments of the Yellow Book plan that were eventually abandoned, we use historical and secondary accounts to determine the earliest year in which right-of-way acquisition, public hearing, surveying, or engineering occurred. Planned Yellow Book segments are color-coded according to how closely they align with present-day limited access roads.

The map shows that some segments predate the Yellow Book, including I-95 in Virginia. Programming for the Capitol Beltway began before the Interstate Highway Act was passed, and it was built largely to plan. Highway segments that were programmed later tended to deviate more from the original plan routes. The alignment for I-66, stretching west from DC to Fairfax, was significantly altered. This was in part due to its late programming date—initial work was not begun until well after the revolts. There was also intense citizen opposition in Arlington and Falls Church, which also contributed to the departure from initial plans. The freeway that was to run northwest from downtown DC through Georgetown along the Potomac was eventually canceled in the face of a freeway revolt.

5.4.2 Evidence from Interstate opening dates across U.S. citiess

For the U.S. as a whole, we lack comprehensive programming dates. Instead, we can use opening dates on Interstate segments according to the PR-511 to understand the changing allocation of highways to neighborhoods according to natural and initial characteristics. Consider the following

[16] More detailed geographic resolution is difficult to find and, when available, often imprecise.

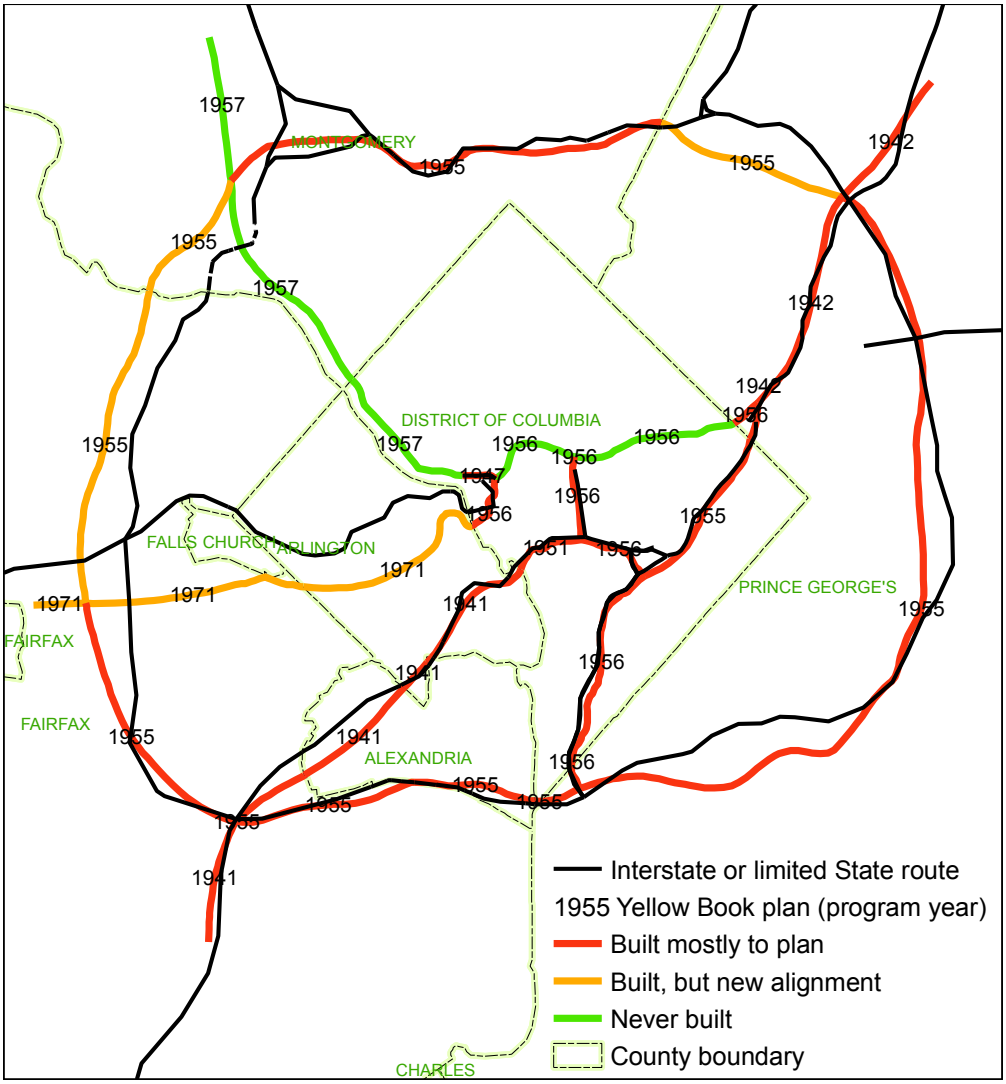


Figure 10: Map of Washington area showing Yellow Book plan and present-day freeways with approximate program year

tract–year regression:

$$1(f_{g[m]t}) = \alpha_{mt} + Z_g'\beta_t + X_g'\gamma_t + \epsilon_{gt} \tag{3}$$

where $1(f_{gt})$ is an indicator for whether tract g is allocated a freeway in year t. A metropolitan area fixed effect α_{mt} ensures that identification comes from variation within metropolitan areas. A vector of persistent factors (Z_g) is included in all specifications, and includes the natural logarithm of distances to the city center, the nearest coastline, river, lake, park, and seaport, and the average slope of the neighborhood. Some specifications also include a vector of initial tract characteristics measured in 1950 (X_g) such as population density, education, or racial composition. The goal of this exercise is to understand what neighborhood factor(s) best predicted selection into the freeway program, and how this predictive relationship evolved over time as the revolts intensified. Thus, we perform this regression separately for the Yellow Book routes and each year between 1955 and 1993, when the PR-511 database ends. The predictive relationship between initial tract characteristics X_g and Z_g and freeway selection in year t varies over time as the freeway network is built out. For each regression, we compute $1(f_{gt})$ based whether tract g is within one-half mile of the freeway network planned or completed in that year. This is a cumulative measure, so that in each year freeway proximity is calculated based on the entire history of freeway openings. This method avoids problems of serial and spatial correlation in the evolution of the highway stock. By 1993, 22 percent of sample tracts were within one-half mile of a built highway. In some specifications, we also perform regressions on only downtown tracts, defined as tracts within 5 miles of city centers. By 1993, 29 percent of these tracts were eventually treated with highways.

Figure 11 shows the results for four regressors of interest that illustrate evolving selection pressures in the building of the Interstates. The vertical axes measure the estimated coefficient of interest ($\hat{\beta}_{it}$). For the linear probability model, the coefficient can then be interpreted as the increase (or decrease) in probability associated with a one-unit increase in the regressor indicated by the panel title. (We also estimate a logit model, with similar results.) Thus, the panels show the evolution of the correlation between the realized highway network and (a) proximity to the coast, (b) proximity to a river, (c) proximity to a historical railroad, and (d) initial 1950 log population density. In each panel, the blue line connects estimates using our full sample of tracts; the green line connects estimates using only "downtown" tracts within 5 miles of city centers. The first points and the dashed horizontal lines show baseline estimates using the Yellow Book ("YB") plan.

Panel (a) shows that in the Yellow Book plan, there was little correlation between freeways and coastlines. However, over the period between 1955 and 1962, and especially from 1958–1960, the actually-built network of Interstates was increasingly constructed in coastal neighborhoods. One set of advantages of coastlines for freeway construction is that they likely eased land assembly issues. Historically, many shore lines tended to be of public or industrial use, easing land acquisition and rights of way for freeways. The fact that the Yellow Book plan did not prioritize coastal routes is somewhat surprising, given the earlier stated priority of using undeveloped land. However, the relatively rapid shift towards coastal highways accords with some other historical evidence. In 1957, the American Association of State Highway Officials (AASHO) issued a new codification of

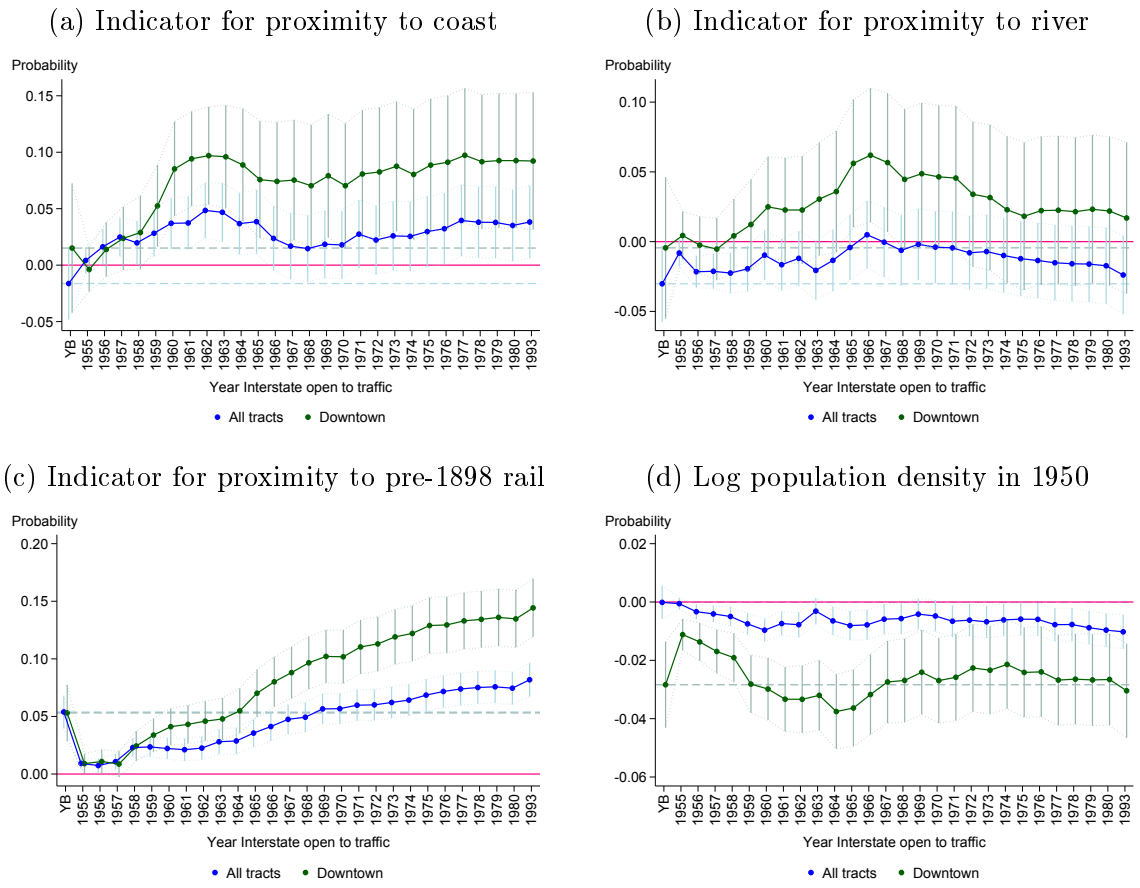


Figure 11: Selection of freeway routes over time by natural or historical factors

Each panel reports estimates from 28 separate regressions for each sample of all tracts (green) and only downtown tracts (blue). First point labeled "YB" shows estimated coefficient and 95% confidence interval from fixed-effects regression of the proximity to the nearest Yellow Book plan route on controls for natural factors and (a) indicator for proximity to the coast, (b) indicator for proximity to a river, (c) indicator for proximity to a pre-1898 railroad, and (d) log population density in 1950. Subsequent points show estimated coefficient from fixed-effects regressions of proximity to the nearest freeway open to traffic by that year. All regressions include controls for log distance to the city center, coast, river, lake, park, seaport, and average slope. Standard errors clustered on metropolitan area.Regressions use observations of 16,530 consistent-boundary tracts in 64 metropolitan areas. Downtown regressions use 5,794 consistent-boundary tracts within 5 miles of city centers.

standards for interstates in the so-called "Red Book." It offered specific suggestions for the location of urban freeways, including selecting blighted areas, adjacent to railroads or shore lines of rivers and lakes, and within or along parks or other large parcels owned by cities or institutions. Further,

> Most cities have land areas outside the central core that lend themselves to the location of new highways. The improvement of radial highways in the past stimulated land development along them and often left wedges of relatively unused land between these ribbons of development. These undeveloped land areas may offer locations for radial routes (AAHSO, p. 89)

Thus, the Red Book emphasized land assembly and acquisition costs as a guiding principle for

freeway route selection. Note, too, that the effect of coastlines on freeway construction was more pronounced in downtown areas, where problems of land assembly and acquisition may have been more difficult.

Panel (b) shows that freeway construction became more likely near rivers over the period 1955–1966, especially in downtowns. Subsequently, there was some reversion, but by 1993 Interstates were still more likely to be sited near rivers compared with the initial Yellow Book plan. Panel (c) shows that built highways increasingly followed historical railroads over time, especially in downtowns, again pointing to possible land assembly factors. Finally, panel (d) shows the evolution of built highways according to initial population density in 1950. Interestingly, by 1993 the correlation between downtown built highways and 1950 population density matches that of the Yellow Book plan. But the Yellow Book plan itself tended to assign downtown highways to less-dense neighborhoods. The fact that in central cities, highways were more likely to be built in initially less-developed areas, is consistent with the selection of neighborhoods on high growth potential seen in the larger IV estimates compared with WLS estimates earlier.

The increasing association between freeway construction and coastlines, rivers, and historical railroads compared with both the Yellow Book plan and the first few years of major Interstate construction, accords with the historical evidence suggesting that urban freeways became increasingly difficult to build in the wake of citizen opposition and the growing freeway revolt.

Next, we turn to evidence on how the social characteristics of neighborhoods predicted freeway selection over time. We add four 1950 tract characteristics X_g as regressors in equation (3): the black share of the population, the college-educated share of the population aged 25 and up, average household income, and population density. As before, we perform regressions separately by year, varying the geography of the Interstate system Initial neighborhood characteristics are all measured in 1950 so do not vary across regression years; instead, their coefficients ($\hat{\gamma}_t$) are allowed to vary. All regresisons include the four 1950 regressors, as well as the controls for natural factors as in the regressions reported in Figure 11. Figure 12 shows estimates from the linear probability model. The four 1950 characteristics are standardized, so the coefficient estimates can be interpreted as the change in probability or odds associated with a one-standard-deviation increase in the neighborhood characteristic.

Panel (a) shows that in the Yellow Book, conditioned on natural factors and other 1950 covariates, black neighborhoods were slightly *less* likely to be assigned freeways. This continued to be true in the first several years of major Interstate construction. Beginning in the early 1960s, built freeways were increasingly located in black neighborhoods (circa 1950), until 1968 or so when the coefficient stabilizes at a level of 0.01. This estimate suggests that a neighborhood with a one-standard deviation increase in the black share in 1950 was 1 percent more likely to be assigned a freeway by 1968. Since the distribution of the 1950 black population share is bimodal, a more relevant comparison may be that the predicted probability of freeway selection in 1968 was more than 6 percentage points higher for an all-black neighborhood compared with an all-white neighborhood, conditioned on natural factors and education, income, and population density.

Panel (b) shows that neighborhoods with high average educational attainment were less likely to receive freeways in the Yellow Book plan. Though the first freeways were uncorrelated with 1950 educational attainment, selection on initial educational attainment worsened steadily from the late 1950s to the late 1960s. The neighborhood college share is a strong predictor of freeway construction. By 1968, a one-standard deviation increase in the 1950 college share predicted a 3 percent decline in the probability of of freeway selection. The predicted gap between the least-educated neighborhood and the most-educated neighborhood was about 26 percent. These dyanmics with respect to educational attainment confirm the predictions of the model of Glaeser and Ponzetto (2017). Interestingly, results shown in panel (c) suggest that, conditioned on race and educational attainment, initial income is not a strong predictor of freeway selection, and the final Interstate network of 1993 closely follows the Yellow Book plan in terms of the conditional correlation with intitial neighborhood income.

In sum, highway planning and construction in the U.S. changed between the Yellow Book plan of 1955 and the late 1960s. Between the late 1950s and late 1960s, natural and historical factors such as coastlines, rivers, and rail roadsbecame better predictors of freeway construction. Compared with intiial plans, freeways also were increasingly built in neighborhoods that were initially more black and less educated. These dynamics are consistent with historical evidence that early freeway planning did not anticipate popular opposition, and that the freeway revolts and subsequent policy changes affected the allocation of freeways in U.S. cities.

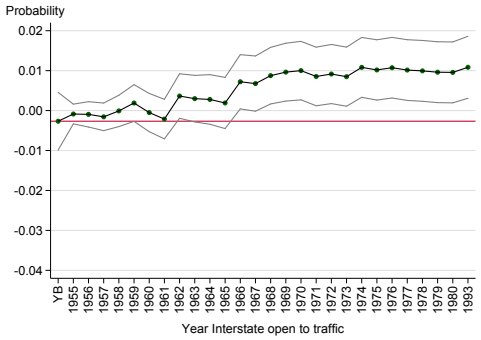
6 A quantitative model of highway disamenities

In this section, we outline a spatial equilibrium model of city structure to measure and quantify the effects of highway disamenities in the context of a realistic urban geography. The model builds on the existing class of quantitative urban/trade models that consider the joint location decisions of employment and population in a city with costly commuting.[17] In this section, we present the basic features of the model as well as a few key derivations important for the solution and estimation of the model.

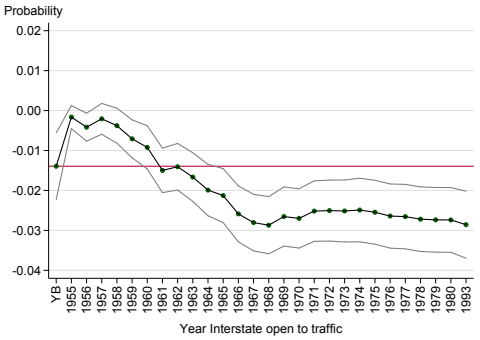
In subsequent sections, the model is used to recover neighborhood-level amenities in the Chicago Metropolitan area by matching cross-sectional variation in population, employment, and travel times. These values are then used to estimate the disamenity resulting from proximity to freeways. Finally, we use the calibrated model to consider a counterfactual experiment, in which the disamenity arising from the highway is mitigated. The importance of the higway disamenity is quantified in terms of welfare, population change, and decentralization.

[17] Our formulation most closely resembles the model developed by Ahlfeldt, Redding, Sturm, and Wolfe (2015). Other examples of related models include Allen and Arkolakis (2014); Monte, Redding, and Rossi-Hansberg (2015); and Severen(2016). For surveys of the literature see Redding and Rossi-Hansberg (2017) and Holmes and Sieg (2015).

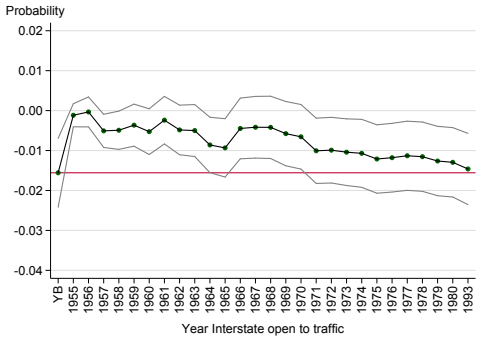
(a) 1950 population share black



(b) 1950 population 25+ share college graduate



(c) 1950 average household income



(d) 1950 population density

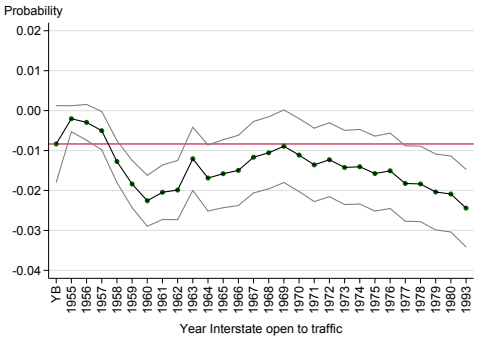


Figure 12: Selection of freeway routes over time by 1950 neighhborhood characteristics

6.1 Geography

There are J locations in the city, each with land area L_j. Land is used both for residential consumption and production. There is a iceberg-style cost of commuting between locations, d_{jk}, that depends on the existing transportation network, such that $d_{jk} = e^{\kappa \tau_{jk}}$, where τ_{jk} is the travel time between two locations and κ is a parameter that describes the relationship between commuting time and costs. To start we will assume the city is closed and thus the total population is fixed at N, and expected utility is endogenous. This assumption allows for the comparison of counterfactual experiments in terms of expected utility. It is straightforward to formulate the model using an open-city assumption, where the city is embedded within a larger economy, and workers are free to leave the city. In this case, the population of workers, N, would be endogenously determined by the outside reservation utility, $\overline{U}$. Note that relative prices and quantities between different locations within the city are independent of this modeling assumption for the functional forms chosen here.

6.2 Workers

Workers are homogeneous and have increasing preferences over consumption, c, land, l, and some neighborhood-specific amenity, B_j.[18] In addition, each individual worker, m, has an idiosyncratic preference for a given commute between home location j and work location k. Preferences are defined by the following utility function,

$$U_{jk,m}(c,l) = \nu_{jk,m} B_j \left(\frac{c}{\beta}\right)^{\beta} \left(\frac{l}{1-\beta}\right)^{1-\beta},$$

where β is the consumption share of income. The idiosyncratic component, $\nu_{jk,m}$, is drawn from a Frechet distribution with a shape parameter ε.[19] For each commuting pair, $\{j,k\}$, workers earn a wage net of commuting costs, $w_k/d_{j,k}$. The workers' budget constraint is then given by, $\frac{w_k}{d_{jk}} = lq_j + c$, where q_j is the price of land at place of residence. Solving the utility maximization problem conditional on wages and rents leads to the following indirect utility for each commuting pair.

$$V_{jk,m}(w_k, q_j) = \nu_{jk,m} \frac{w_k}{d_{jk}} B_j \ln q_j^{(\beta-1)}$$

Once an individual worker has entered the economy, they will choose a home and work location that that maximizes utility. The probability that a worker will live in location j and commute to k is given by,

[18] We assume direct consumption of land and thus do not explicitly model the production of housing. This is equivalent to assuming capital is mobile and that the housing production function follows a Cobb-Douglas functional form. For evidence in support of this assumption See Thorsnes (1997) and Combes, Duranton, and Gobillon (2017).

[19] Formulations of this model often include location-specific mean-shifting terms in the Frechet distribution. These are important when measuring workplace amenities or when wages are used in estimation. Given our focus and identification strategy, we do not explicitly include these terms, and thus they are subsumed by the location specific amenity and productivity terms, B_j and A_k.

$$\pi_{jk} = \frac{\left(d_{jk} q_j^{1-\beta}\right)^{-\varepsilon} \left(B_j w_k\right)^{\varepsilon}}{\sum_{j'=1}^{J} \sum_{k'=1}^{J} \left(d'_{j'k'} q_{j'}^{1-\beta}\right)^{-\varepsilon} \left(B_{j'} w_{k'}\right)^{\varepsilon}}, \tag{4}$$

and the probability that a worker will commute to location k, conditional on living in j, is given by,

$$\pi_{jk|j} = \frac{\left(\frac{w_j}{d_{jk}}\right)^{\varepsilon}}{\sum_{k'=1}^{J} \left(\frac{w_{j'}}{d_{jk'}}\right)^{\varepsilon}}.$$

This implies the commuting market clearing condition:

$$N_{Wk} = \frac{\left(\frac{w_j}{d_{jk}}\right)^{\varepsilon}}{\sum_{k'=1}^{J} \left(\frac{w_{j'}}{d_{jk'}}\right)^{\varepsilon}} N_{Rj} \tag{5}$$

Where N_{Wk} represents the measure of workers working in location k, and N_{Rj} represents the measure of workers residing in location j. Total residential land consumption in a location is calculated by summing the land demand for all workers in a location.

$$L_{Rj} = (1-\beta) \frac{N_{Rj}}{q_j} \sum_{k=1}^{J} \pi_{jk|j} \frac{w_k}{d_{jk}} \tag{6}$$

6.2.1 Highway Disamenities

An important consideration for the current application is the form of the location amenity B_j. In general, B_j contains all of the components that determine the amenity value of a location, with the exception of access to jobs, which is handled by the commuting structure of the model. These amenities could include innate features, such as access to beaches or city views, or endogenous features, both public and private, including access to parks, schools, restaurants, or stores. We start with the following form of the amenity function.

$$B_j = b_j g\left(d_H\right),$$

where b_j is an exogenous amenity component, and $g\left(d_H\right)$ describes the disamenity at a given distance to the highway, d_{Hj}. For now we will assume that the disamenity is a simple function of distance to the highway and does not depend on endogenous variables.[20] The highway disamenity takes the following form.

[20] For now we do not explicitly model endogenous amenities that arise from density as those found in Ahlfeldt, Redding, Sturm, and Wolfe (2015). One particular challenge is that our empirical results suggest that part of the disamenity effect of highways arises from changes in access to local amenities through barrier effects, thus directly affecting the kinds of neighborhood spillovers that have been estimated previously in the literature. In future extensions, a more complex formulation of the model could be used to decompose the disamenity into barrier effects, land use exclusion or other spatial externalities.

$$g\left(d_H\right) = 1 - b_H e^{-\eta d_{Hj}} \tag{7}$$

where b_H is represents the magnitude of the disamenity, and η describes the attenuation of the disamenity across space. This form is isomorphic to a cost that decays exponentially with distance to the highway, and similar forms have been used to study the spatial costs of noise or pollution externalities.[21] We will show that this functional form is consistent with estimated amenities near freeways.

6.3 Production

There is a single final good that is costlessly traded and produced under perfect competition. Production in each location is given by the following a constant returns function.

$$Y_k = A_k L_{Wk}^{1-\alpha} N_{Wk}^{\alpha},$$

where A_k is total factor productivity, L_{Wk} is total land used for production in each location, N_{Wk} is total employment in each location, and α is the labor share in production. For our baseline analysis, we assume that total factor productivity for each location is exogenous.[22] This does not affect the calibration or estimation of highway disamenities. However, it does play a role in counterfactual simulations. Adding production spillovers is a straightforward extension which can be modeled as the following.

$$A_k = a_k x_k^{\eta}$$

where a_k is the exogenous productivity of a location, and x_k, is a production externality that arises from clustering of economic activity, and is given by,

$$x_k = \sum_{k'=1}^{J} e^{-\delta \tau_{kk'}} \left(\frac{N_{Wk}}{L_k}\right).$$

By solving the profit maximization problem of the firm, it can be shown that total commercial land use in each location is given by the following relationship.

$$L_{W_k} = N_{W_k} \frac{(1-\alpha)}{\alpha} \frac{w_k}{q_j} \tag{8}$$

6.4 Equilibrium

To define equilibrium, first assume that land area and travel times $\{L_j, d_{jk}\}$, as well as total population N, are exogenous; we will directly observe these objects in the data. In addition, values for the models parameters $\{\alpha, \beta, \varepsilon\}$ and location fundamentals, $\{A_k, B_j\}$, are known. Equilibrium

[21] See Nelson (1982) or Henderson (1977) for examples in the literature.

[22] We also assume there is no productivity disadvantage of locating near a highway. We show in the appendix, that there is no empirical evidence for such a production disamenity.

is then defined as a vector of prices $\{q_j, w_j\}$ and a vector of quantities, $\{N_{Hj}, N_{Wk}, L_{Hj}, L_{Wj}\}$ such that: (1) labor markets clear through the commuting market clearing condition from Equation 5, (2) Land markets clear, such that land demand from Equations 6 and 8 sum to land supply, L_j in each location, and (3), total population equals N.[23]

In practice, the model is solved iteratively. A detailed description of the solution method can be found in Appendix XX. In order to extend the model to an open-city framework, total population becomes endogenous and an additional condition of equilibrium is that expected utility is equal to the reservation utility. Formally, this is written as,

$$E[u] = \Gamma\left(\frac{\varepsilon - 1}{\varepsilon}\right)\left[\sum_{j'=1}^{J}\sum_{k'=1}^{J} r_{j'}s_{k'}\left(d_{j'k'}q_{j'}^{1-\beta}\right)^{-\varepsilon}\left(B_{j'}w_{k'}\right)^{\varepsilon}\right]^{1/\varepsilon} = \overline{U}, \tag{9}$$

where Γ is the Gamma function.

7 Calibration and Estimation of Highway Disamentities

This section outlines the procedure for calibration of the model parameters and the estimation of the highway disamenity function. The strategy is to first use estimates in the literature to set several global parameters in the model. These parameters, along with tract-level data on population, employment, land area, and commute times, allow for the recovery of location-specific amenity and productivity values using the structure of the model. The recovered amenities are then used to estimate the highway disamenity function by fitting the relationship between recovered location amenities and the distance to major highways.

7.1 Calibration

The model is calibrated using data covering the Chicago metropolitan statistical area. Data is drawn from the 2000 Census Transportation Planning Package, which provides information on tract-level employment, worker population, land area, and tract-to-tract commute times.[24] The first step in the calibration procedure is to set values for four general parameters using estimates in the literature. The sensitivity of these selections is explored in detail. For the consumption share parameter, β, we use a value of 0.96,[25] and for the labor share in production we choose 0.97.[26] The value of κ, which is interpreted as the wage value of time spent commuting is set to be approximately equal to the wage rate which corresponds to a value of 0.02.[27] Lastly, we set the

[23] Ahlfeldt, Redding, Sturm, and Wolfe (2015) provide proofs of existence and uniqueness, which extend in a straight forward way to the simplified environment here.

[24] Commute times are only observed for origin-destination pairs that have non-zero commuting in the data. We use a local adaptive-bandwidth kernel density estimator to interpolate unobserved values. The data also includes tract-to-tract commuting flows, which we do not use at this time.

[25] See Brinkman (2016); Davis and Ortalo-Magn (2007); and Davis and Palumbo (2008), for details on the land share of housing and consumption.

[26] See Brinkman(2016), Ciccone (2002) and Rappaport (2008).

[27] See Van Ommeren and Fosgerau (2009); and Small (2012)

value of ε to 3.3, which is approximately in the middle of the range of estimates in the literature.[28]

Once we have calibrated general parameters, $\{\kappa, \alpha, \beta, \varepsilon\}$, the next step is to estimate the location-specific productivity and amenity values, $\{A_k, B_j\}$. In this stage, the goal is to recover overall amenity and productivities, that may contain both endogenous and exogenous components, including highway disamenities. These values are exactly identified using only data on residential population, employment, land area, and commute times.[29] The intuition behind identification is that places with high population density and less access to jobs have higher amenities. Likewise, locations with high employment density and less access to workers (longer commutes) have higher productivity.

We observe residential population (N_{Rj}), employment (N_{Wk}), land area (L_j), and commuting costs ($d_{jk} = e^{-\kappa \tau_{jk}}$). The following equations allow for the calibration of A_k and B_j. Rewriting equation 5, we get the following equation that can be used to solve for wages paid at each location, w_j.

$$w_k = \left(\frac{1}{N_{W_k}} \sum_{j=1}^{J} \frac{\left(\frac{1}{d_{jk}}\right)^{\varepsilon}}{\sum_{k'=1}^{J} \left(\frac{w_{k'}}{d_{jk'}}\right)^{\varepsilon}} N_{Hj} \right)^{-\frac{1}{\varepsilon}}$$

The land market clearing condition and the land-consumption equations for firms and workers (Equations 6 and 8), are used to derive the following equation for land rents in each location.

$$q_j = \frac{1}{L_j} \left(N_{W_k} \frac{(1-\alpha)}{\alpha} w_k + (1-\beta) N_{Hj} \sum_{k=1}^{J} \pi_{jk|j} \frac{w_k}{d_{jk}} \right)$$

Next, we use these wages and rents to recover the location-specific amenities, B_j, by combining Equations 4 and 9.

$$B_j = \left(\frac{N_{Hj}}{N}\right)^{\frac{1}{\varepsilon}} \left(\frac{\overline{U}}{\Gamma\left(\frac{\varepsilon-1}{\varepsilon}\right)} \right) \left(q_j^{1-\beta} \right) \left(\sum_{k=1}^{J} \left(\frac{w_k}{d_{jk}}\right)^{\varepsilon} \right)^{-\frac{1}{\varepsilon}}$$

Lastly, solving the profit maximization problem of the firm, and assuming zero profits, gives the following expression for location-specific productivity.

$$A_k = \left(\frac{w_k}{\alpha}\right)^{\alpha} \left(\frac{q_k}{(1-\alpha)} \right)^{1-\alpha}$$

Using the baseline specification, the calibrated values of the amenities for different tracts in the Chicago MSA, B_j, are shown in Figure 13. The values are in logs relative to the mean amenity in the city. The map shows that in general, higher amenity neighborhoods are located north of the city, especially in neighborhoods along Lake Michigan.

[28] See Monte, Redding, and Rossi-Hansberg (2015); Ahlfeldt, Redding, Sturm, and Wolfe (2015); and Severen (2017)

[29] We choose to use land area, population, and employment, given that they are precisely and easily observed quantities. The model could also be calibrated using land values, house prices, or wages.

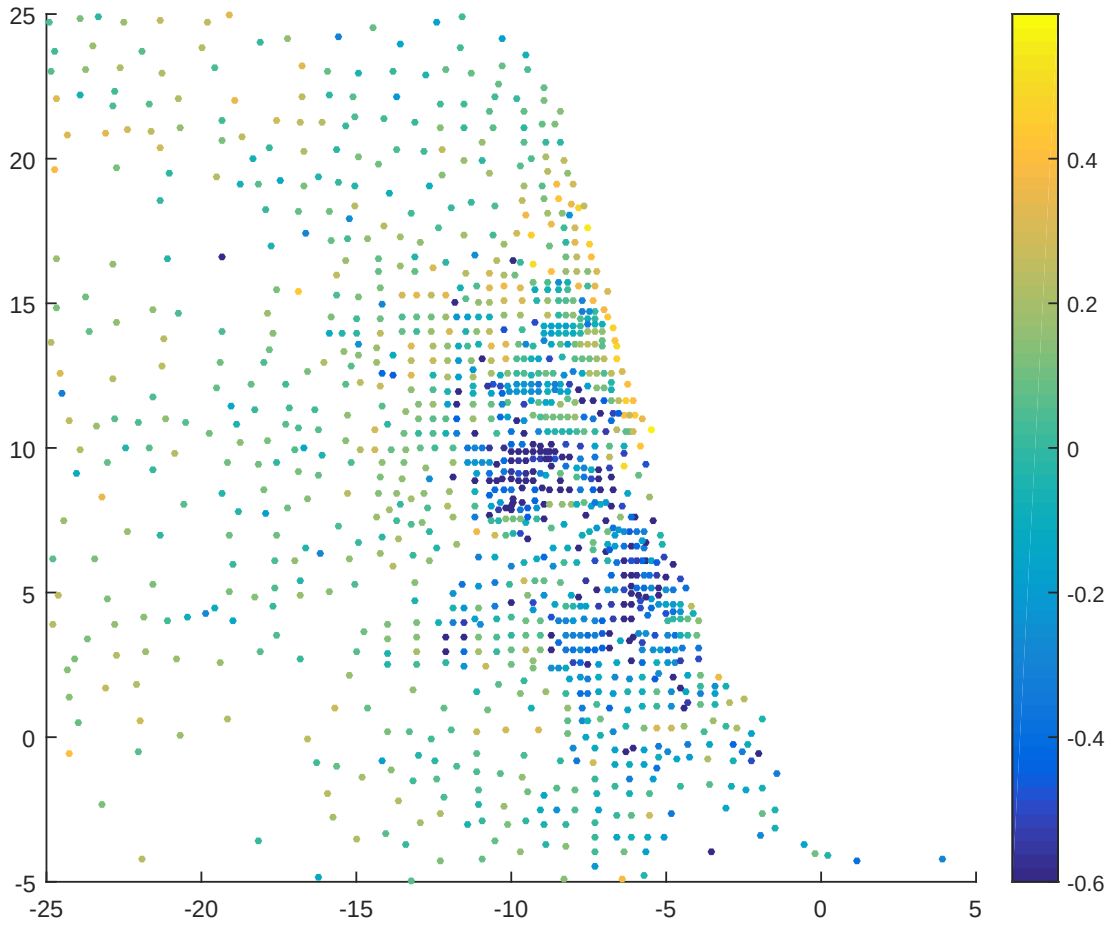


Figure 13: Observed amenities in Chicago

This figure maps the calibrated amenity values for each census tract in the Chicago MSA for the baseline specification. The values are in the log of the amenity values divided by the mean neighborhood amenity in the MSA. The x and y scales are distances in miles.

7.2 Estimation of the Highway Disamenity

Next, we turn to the influence of highways on local neighborhood amenities. The parameters of highway disamenity function are estimated by using a nonlinear least-squares method to fit the function in Equation 7 to the calibrated amenity values, B_j.[30] Specifically, the estimator of the vector $\{b_H, \eta\}$ is given by,

$$\{\hat{b_H}, \hat{\eta}\} = argmin_{\{b_H,\eta\}} \sum_{j=1}^{J} (B_j - (1 - b_H e^{-\eta d_{Hj}}))^2.$$

Figure 14 shows a plot of the recovered amenity values and the fitted highway disamenity function for the baseline calibration, where we estimate values of .21 for b_H and .98 for η. The interpretation of these parameters is that neighborhoods immediately adjacent to the highway have an amenity reduction of 21 percent, and this effect attenuates by 95 percent at three miles away from the highway. The relationship between amenity values and proximity to a highway is obvious from the plot, and the qualitative relationship is very robust to the choice of calibrated parameters.[31]

One concern is that there might be a selection bias due to the nonrandom location of highways. To deal with this problem, we return to the instrumental variable strategy used in the reduced-form estimates. We use a two-stage process, whereby the predicted distance to a highway is recovered by regressing the distance to a highway on the instruments for planned routes, shortest-distance, historical railroads, and exploration routes. The highway disamenity function is then fitted to these predicted distances using a non-linear least squares method, as before.[32]

The estimates of the highway disamenities are shown in Table 4 for various calibrated parameter vectors, shown in columns 1-4. The table shows both the non-linear least squares estimates (columns 5-8), as well as those using a two-stage IV strategy (columns 9-12). The baseline estimates, discussed previously, are shown in the top row, with the other rows showing the sensitivity to specific calibrated parameters. All parameter estimates are significant and positive for all specifications. However the magnitudes of the estimated parameters are sensitive to the different specifications. In particular, the value of the Frechet parameter, ϵ, plays a particularly important role in the estimates. For larger values of epsilon, the estimates of the disamenity are considerably smaller.[33]

8 Counterfactual Policies

In this section, we present the results of a counterfactual policy simulation whereby the negative effects of highways on neighborhoods are mitigated. Specifically, we assume that transportation costs remain unchanged, but remove the disamenity from the highway and then recompute the equilibrium for the economy. This is accomplished by setting the parameters of the disamenity

[30] We fit the function in levels, which is a consistent estimator of the parameters. A more natural method might be to fit the function in logs, but this would require truncating the sample to remove zeros.

[31] Note, that we do the same exercise for location productivity, A_k, but we find no relationship with distance to highway. These results are shown in Appendix XX.

[32] Note that we do not include a correction to the standard errors for the first-stage regressions.

[33] This suggest further investigation of this parameter is warranted.

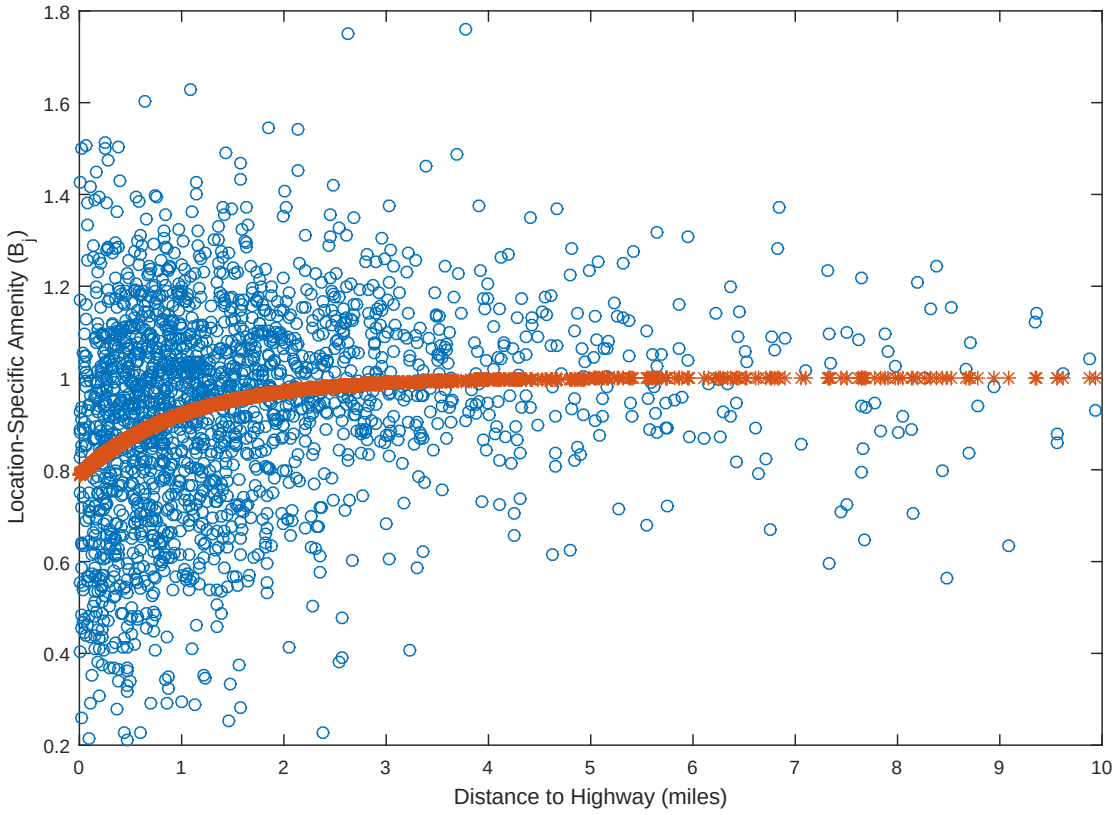


Figure 14: Amenities and proximity to freeways

This figure plots the recovered amenity values from the calibration, B_j, along with the fitted highway disamenity function for the baseline case against the distance to a highway. The values are normalized by dividing by a scale factor such that the disamenity function approaches one asymptotically.

Table 4: Estimates of disamenity parameters and sensitivity to calibration

Calibrated Parameters				Least Squares				IV			
κ	β	α	ϵ	b_h	**(std. err.)**	η	**(std. err.)**	b_h	**(std. err.)**	η	**(std. err.)**
0.002	0.960	0.970	3.300	0.212	0.011	0.981	0.087	0.280	0.009	0.473	0.026
0.001	0.960	0.970	3.300	0.209	0.012	1.027	0.093	0.273	0.010	0.487	0.027
0.004	0.960	0.970	3.300	0.218	0.011	0.894	0.076	0.295	0.009	0.446	0.023
0.002	0.920	0.970	3.300	0.184	0.016	1.662	0.209	0.144	0.011	0.510	0.062
0.002	0.980	0.970	3.300	0.234	0.010	0.742	0.056	0.342	0.009	0.450	0.019
0.002	0.960	0.985	3.300	0.214	0.011	0.985	0.086	0.280	0.009	0.475	0.026
0.002	0.960	0.940	3.300	0.209	0.011	0.977	0.088	0.281	0.009	0.471	0.025
0.002	0.960	0.970	1.500	0.372	0.017	0.709	0.059	0.571	0.020	0.674	0.030
0.002	0.960	0.970	7.700	0.100	0.009	1.758	0.229	0.081	0.007	0.565	0.068

This table shows the estimates and standard errors of the highway disamenity parameters, b_H and η, for various calibrated parameter vectors, shown in columns 1-4. The table shows both the non-linear least squares estimates (columns 5-8), as well as those using a two-stage IV strategy (columns 9-12).

function to zero. This policy is analagous to real-world policies that attempt to mitigate these negative effects by burying or capping freeways particularly in urban areas. There are many examples of such projects, with the most prominent being the "Big Dig" in Boston where a large section of the highway through the central part of the city was buried under ground. Estimates of the total cost of that project were over $20 billion. With this analysis, we will attempt to understand the benefits of such a project.

First we simulate the effects of complete mitigation of highway disamenities in the the Chicago MSA. For all the exercises in this section, we model a closed city, where population in the entire city remains constant, which allows us to consider the effect on expected utility.[34] Figure 15 shows the change in population density for the counterfactual experiment using our baseline parameters. This figure shows prominently the large gains in population near the freeways. In addition, the relative gains are considerably larger in high-amenity neighborhoods.

We consider two primary outcomes from the policy experiment. The first is the change in expected utility, and the second is the change in the share of worker population within 5 miles of the CBD. In the data, there are 351,465 employed residents living within five miles of the CBD, representing 8.7 percent of the total population. The results are shown in Table 5 for various calibrations. The utility values represent the ratio of the counterfactual expected utility relative to the simulated economy that includes highway disamenities.

Table 5: Results of simulated mitigation policy

κ	β	α	ϵ	**Utility Change**	**% change <5mi**
0.002	0.960	0.970	3.300	1.079	1.225
0.001	0.960	0.970	3.300	1.075	1.221
0.004	0.960	0.970	3.300	1.088	1.234
0.002	0.920	0.970	3.300	1.042	1.158
0.002	0.980	0.970	3.300	1.110	1.265
0.002	0.960	0.985	3.300	1.080	1.226
0.002	0.960	0.940	3.300	1.078	1.226
0.002	0.960	0.970	1.500	1.192	1.204
0.002	0.960	0.970	7.700	1.022	1.195

This table shows the results of counterfactual experiments where the negative effects of highways are removed, and the economy is resimulated. The utility values represent the ratio of expected utility relative to the intitial calibration. The last column shows the change in employed residents relative to the initial calibration. The simulations use a closed-city assumption, such that total population is fixed.

For the baseline calibration (first row), the counterfactual results suggest that the aggregate utility gains are quite large, exhibiting a 7.9 percent gain in expected utility in the economy. While the magnitude is extremely large, it should be noted that this is an extremely expensive policy intervention akin to burying all highways in the metro area. In addition, there is a large centralization effect resulting from the policy with a 22.5 percent gain in population within five

[34]It would be straightforward to perform the same analysis using an open-city framework. Note that the relative effects on different neighborhoods are not dependent on this modeling choice. i.e. rents, population, employment, and wages are the same in both specifications up to a scale factor.

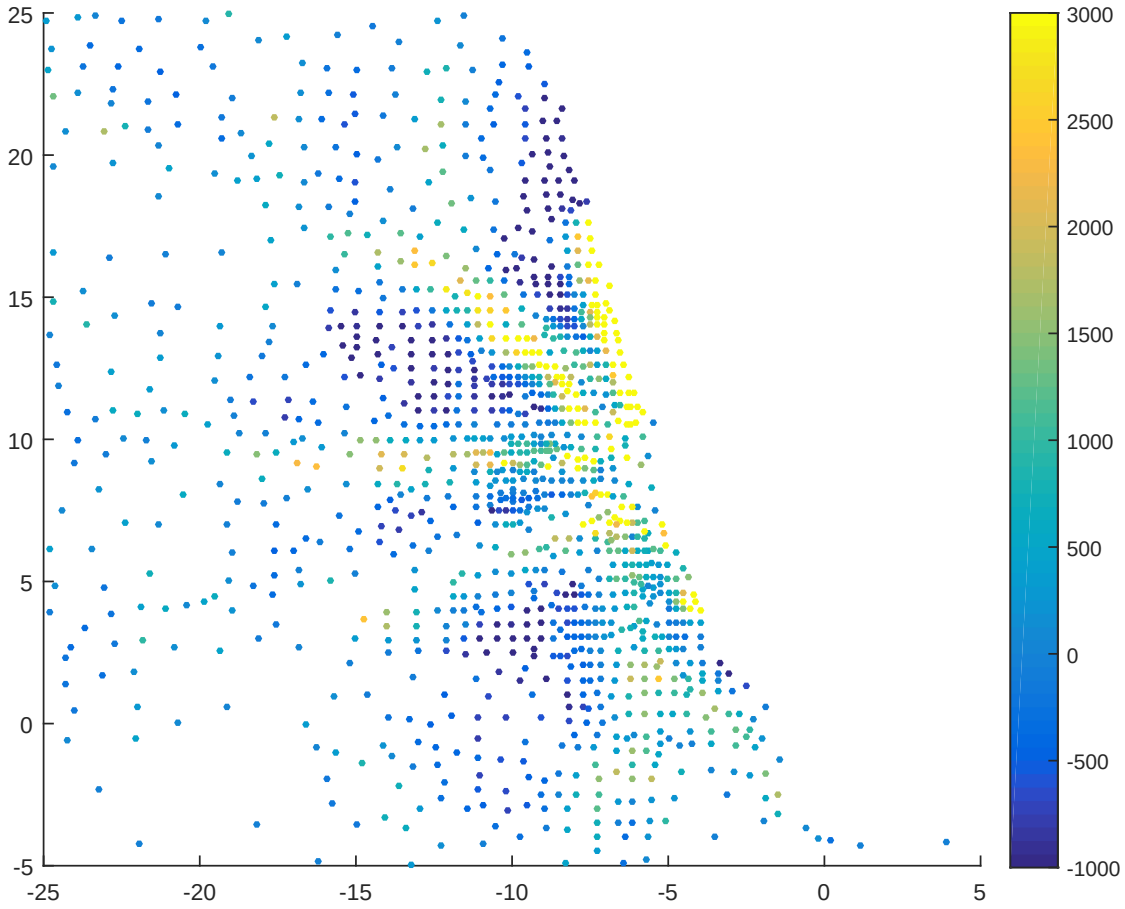


Figure 15: Change in population density after mitigation of freeway disamenities

This figure shows the effect on population density for the counterfactual experiment where all negative effects from highways are mitigated for the entire metropolitan area. The colors represent changes in population density per square mile. The x and y scales are distances in miles.

miles of the CBD at the expense of population in outlying areas. The magnitude of utility gains are quite sensitive to calibration choices, ranging from a 2 percent gain up to 19 percent, with the results being most sensitive to the choice of ϵ. The centralization result, on the other hand, is fairly stable, with increases in population within 5 miles to the CBD ranging from 15 percent up to 23 percent.

Next we consider the relative importance of mitigation for different locations in the city. This is done in several ways. First, we consider an policy where mitigation is only implemented for locations within a certain distance of the CBD. We then plot the change in expected utility for the entire city as the radius is moved further and further out, until all highway disamenities are mitigated as in the previous excercise. The results are shown in Figure 16. What this figure suggests is that the marginal gains in expected utility are higher for locations close to the center as exhibited by the steeper slope.

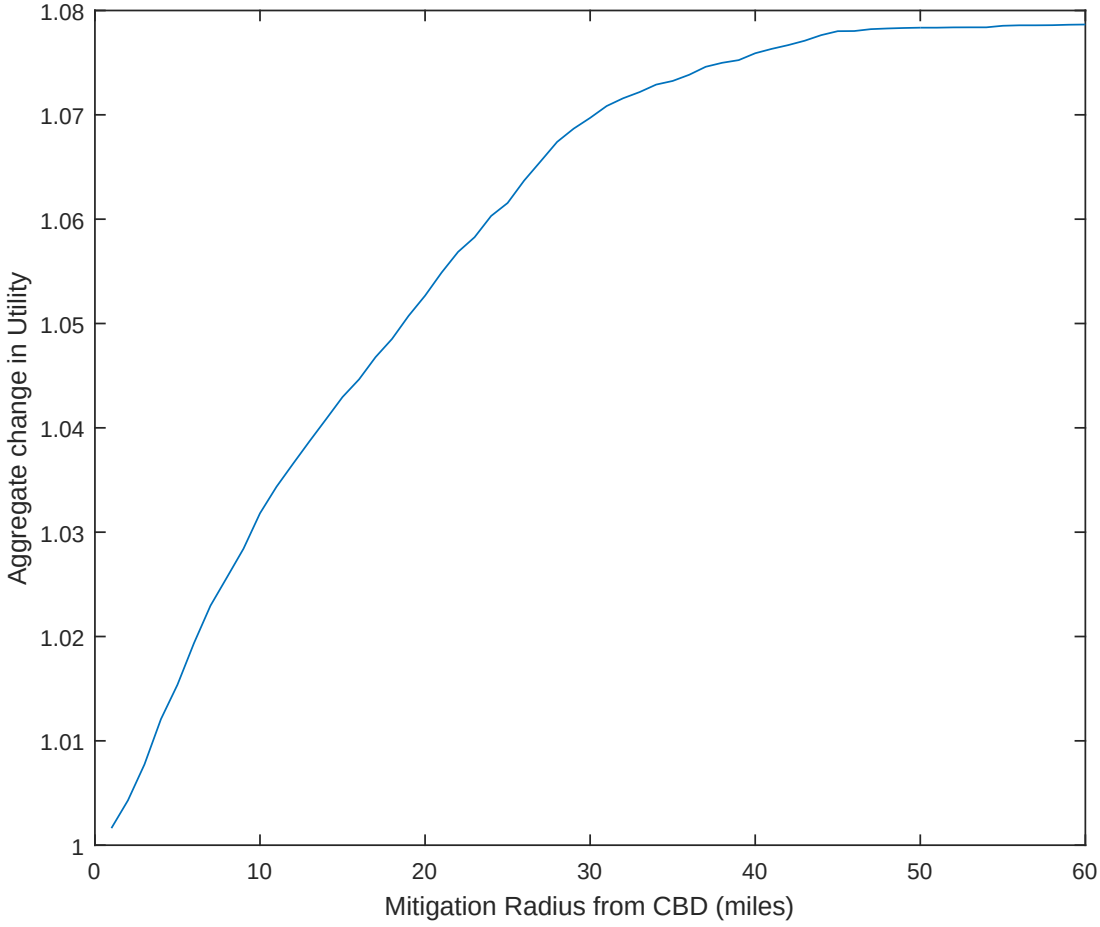


Figure 16: Change in aggregate utility after mitigation of freeway disamenities at different radii

Lastly we consider a policy where each location mitigates the highway disamenity unilaterally.

Specifically, we turn off the negative effects of the highway for all neighborhoods at a given radius and measure the percentage change in population for only that location. These results are shown in Figure 17. If the mitigation policy were only applied to neighborhoods within 1 mile of the CBD, population gains in those neighborhoods would increase by 70 percent. However, if the mitigation policy were only applied for locations between 10 and 20 miles from the CBD, the gains would be considerably smaller at around 30 percent. This is suggestive that mitigation policies may be more effective close to the CBD, however, this result is somewhat mechanically driven by the fact that locations near the center are more likely to be exposed to negative effects of highways. This result also provides evidence as to why political opposition to freeway projects is more often observed in centrally located urban neighborhoods.

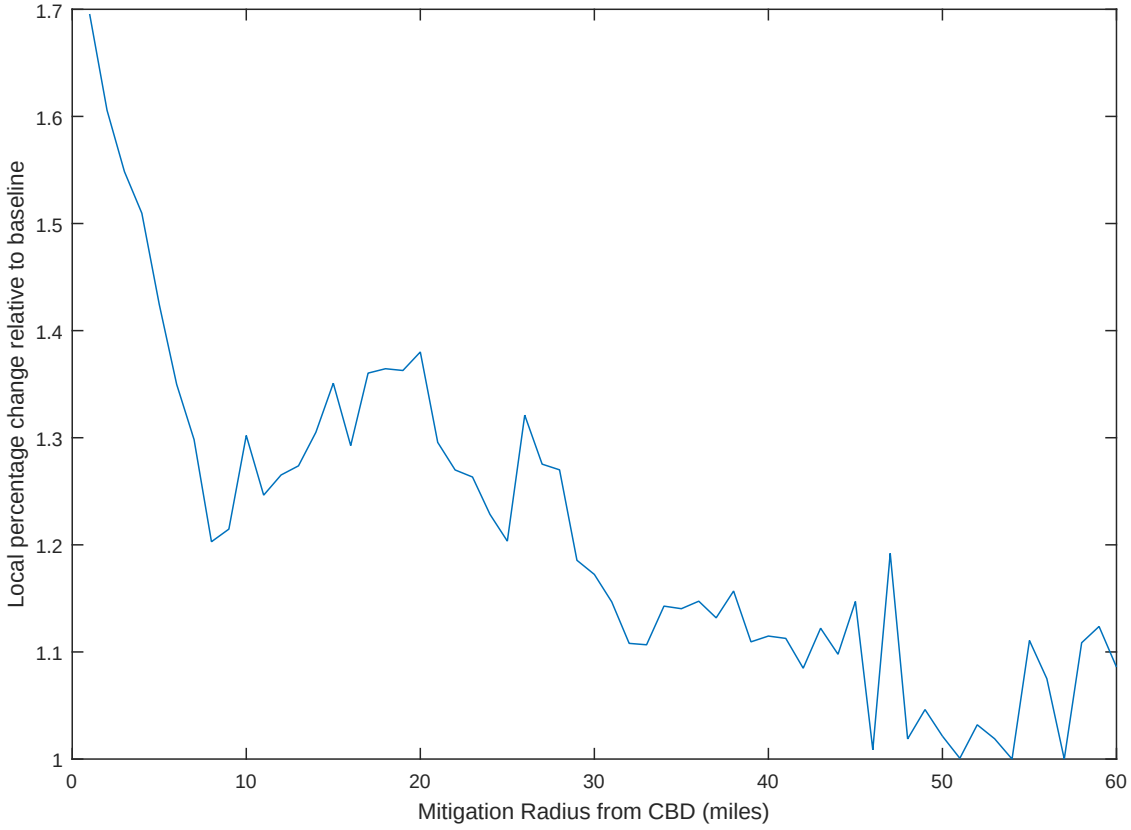


Figure 17: Effect of each location unilaterally mitigating highway disamenity: Percent change in population relative to baseline.

9 Conclusions

To come.

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