Freeway revolts!

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April 17, 2018

Preliminary and incomplete
(Most recent version)

Abstract

Freeway revolts were widespread protests that erupted across the U.S. following early urban Interstate construction in the mid-1950s. We present theory and evidence from a variety of sources—including panel data on neighborhoods in U.S. cities, 1950–2010 and changes in travel behavior since the 1950s—to show that reduced quality of life from freeway disamenities inspired the revolts, affected the allocation of freeways within cities, and changed city structure. First, actual freeway construction increasingly diverged from initial plans in the wake of the growing freeway revolts and subsequent policy responses, especially in central neighborhoods. Second, freeways caused slower growth in population, income, jobs, and land values in central areas, but faster growth in outlying areas. These patterns suggest that in central areas, freeway disamenity effects exceeded small access benefits. Third, in a quantitative general equilibrium spatial model, the aggregate welfare benefits from burying or capping highways are large and concentrated downtown, consistent with opposition to urban freeways in central neighborhoods. Disamenities from freeways, versus their commuting benefits, likely played a significant role in the decentralization of U.S. cities.

Keywords: central cities, urban growth, amenities, commuting costs, suburbanization, highways
JEL classification: N72, N92, O18, Q53, R14, R23, R41, R42

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 Acknowledgements: We thank David Mok-Lamme and Cameron Fen for outstanding research assistance; Jon Hallas, Cris McCollum, Roberto Sarmiento, and Kermit Wies for help finding travel survey data; Gabriel Ahlfeldt, Nate Baum-Snow, and Dan McMillen for sharing data; and Richard Weingroff for advice on highway history and data. Nate Baum-Snow, Jonathan Dingel, Ed Glaeser, Jonathan Hall, Jake Krimmel, Osborne Jackson, and conference and seminar participants at the Federal Reserve System Committee on Regional Analysis, the North American and European meetings of the Urban Economics Association, the Federal Reserve Bank of Cleveland, the University of Nebraska–Lincoln, the NBER Summer Institute, the NBER Trade and Geography conference, the University of British Columbia, the University of Colorado–Boulder, the University of Southern California, and the University of Wisconsin provided helpful comments. First version: June 8, 2016.

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. 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,[1] 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 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

[1] In 1955, residents in the path of the Western Freeway in San Francisco organized to fight its proposed route (Dimento and Ellis, p. 137).

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).

Second, 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).

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 Severen(2016).[2] 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. It also suggests that freeway disamenities, as opposed to access benefits, played a significant role in the decentralization of U.S. cities.

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

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

of central cities in response to lower transportation costs is consistent with the monocentric city 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 freeway disamenities

What are the effects of freeways disamenities? To fix ideas, consider a monocentric city as modeled by von Thunen (1826), Mills (1967), and others.[3] Workers choose where to live and commute to a city center, an exogenous point in space.[4] Commuting is costly, so workers face a tradeoff between higher land prices and shorter commutes. In equilibrium, prices adjust so that utility is equalized at every location, and both population density and land prices decline with distance to the center. Figure 1, panel A illustrates this equilibrium pattern of declining population density with distance to the city center, depicted as a star.

When a freeway is constructed that connects the city center to outlying areas, there will be several effects. The first well-known effect is that access to the city center improves via faster commutes. These access benefits vary. Locations near the city center will not benefit significantly,

[3]The purpose here is to provide a simple model to provide intuition and structure our reduced-form analysis. A richer model of city structure is presented in Section 9.

[4]This analysis may also apply to other regional destinations, not just work commutes.

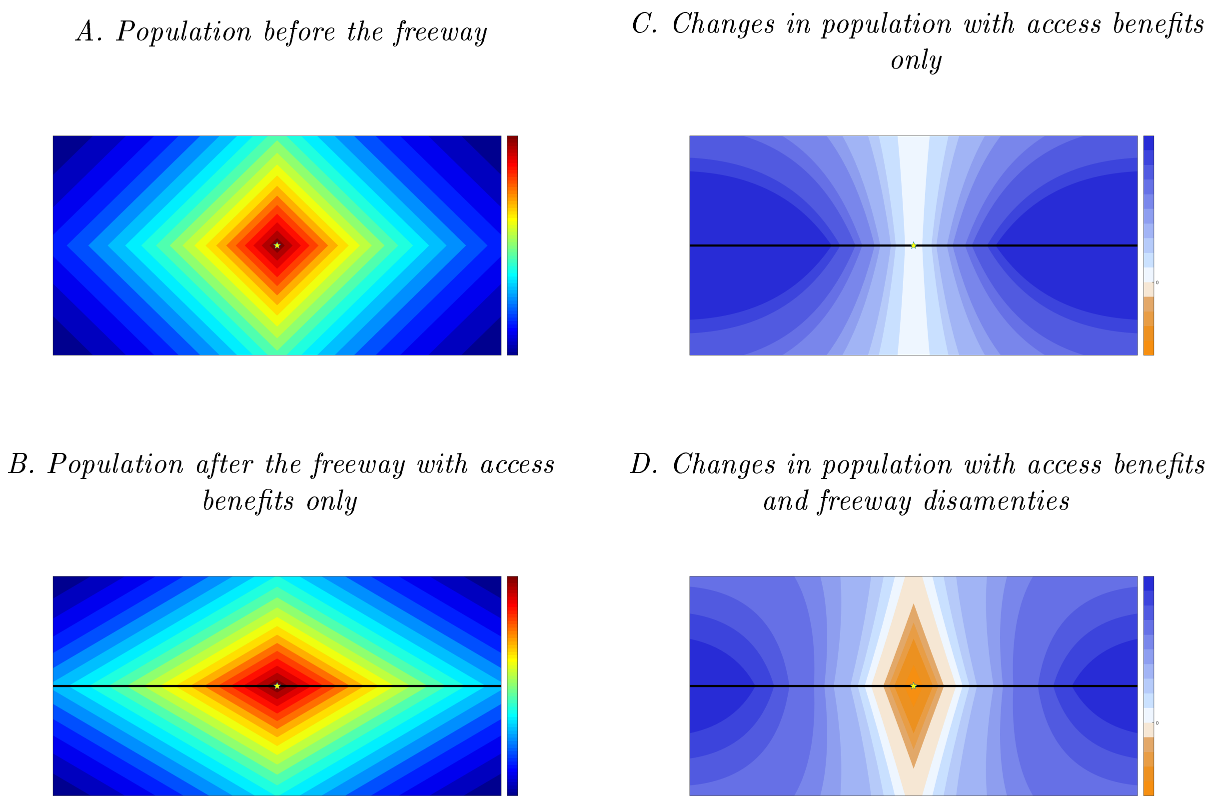


Figure 1: Population effects of a freeway in a monocentric city

since the new freeway has little effect on (already-low) commuting costs. Locations farther from the center benefit more, especially if they are near the new freeway. Thus, access benefits cause relative population growth in locations that are farther from the city center and closer to the freeway. Figure 1, panel B shows that a freeway aligned along the horizontal axis connecting the city center to outlying areas leads to population growth and decentralization, with population spreading out along the newly-constructed freeway. Alternatively, Figure 1, panel C shows *changes* in population after freeway construction. Locations near freeways in outlying areas see the largest increases in population; population in central areas is little changed.[5]

A second effect of the new freeway is that quality of life declines in neighborhoods because of freeway disamenities. These disamenity effects may stem from several sources, including the loss of developable land, pollution or noise externalities, or barrier effects, i.e., reductions in access between neighborhoods severed by freeways. These may arise in all locations, independent of distance to the city center. Thus, the net effect of both the access and disamenity channels will vary by

[5]Our analysis here assumes an open city, where equlibrium utility is fixed at an outside reservation level and total population adjusts. However, a key testable prediction is unchanged in the closed-city case: that freeway disamenities faster relative population growth in outlying neighborhoods near freeways compared with central neighborhoods near freeways.

location. For central neighborhoods, the disamenity effects will dominate given that access benefits are minimal, and population growth will be slower in neighborhoods near the freeway. For locations far from the center, the net effects are ambiguous. If the access benefits dominate the disamenity effects, then population growth will be larger near the freeway in outlying areas. Unambiguously, population growth near freeways will be relatively larger in outlying areas compared with central areas. Figure 1, panel D shows changes in population when freeways have access benefits *and* disamenities. As in the no-disamenities case, locations near freeways in outlying areas see the largest increases in population. (In the case shown, access benefits dominate freeway disamenities at the periphery.) In contrast to the no-disamenities case, locations near freeways in central areas see the largest declines in population.

This discussion offers several predictions. The decline in commuting costs leads to population gains in outlying neighborhoods, especially in those closest to new freeways. Freeway disamenities lead to population declines in central neighborhoods, especially in those closest to new freeways. Similar predictions can be made about changes in land prices, the sorting of income groups, or within a closed-city framework.[6] In general, a common prediction is that *if* freeway disamenities are important, then their effects will show up most in central neighborhoods, *especially* near freeways. We evaluate these predictions, as well as alternative mechanisms, in the following sections.

3 Data

Our analysis combines data from multiple sources. (Details can be found in the data appendix.) One, we use consistent-boundary census tract data for 64 U.S. metropolitan areas (Lee and Lin, 2018).[7] Census tables provide information about population and housing for each tract in each Census year between 1950 and 2010, inclusive. For each tract, we compute distance to the city's center, a point in space identified by Fee and Hartley (2013) using the 1982 Census of Retail Trade. We also spatially match tracts to natural features such as coastlines, lakes, rivers, and slope (Lee and Lin, 2018) as well as other factors, such as historical rail routes (Atack, 2016).

Two, each tract is also matched to the nearest present-day freeway from the National Highway Planning Network (NHPN) (2016), a database of line features representing highways in the United States. From the NHPN we select all limited access roads, which include Interstate highways as

[6]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. (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)). They also depend on whether or not commuting costs scale with income and the importance of fixed costs as studied by LeRoy and Sonstelie (1983). However, if there is a disamenity effect from being located close to the freeway, then it will be more important for sorting in central neighborhoods. In suburban neighborhoods, the sorting patterns after freeway construction will depend more on the reduced commuting costs. The fact that there are potentially multiple sources of heterogeneity makes overall patterns ambiguous.

[7]Since tract boundaries occassionally change over time, these are data are normalized to 2010 boundaries using area weights, or, in later years, block population weights. Our analysis is limited to the 64 metropolitan areas with tract-level measures in 1950. These 64 metropolitan areas contained about one-third of the total U.S. population in 2010.

well as certain U.S., state, and local highways that offer full access control (i.e., those that prohibit at-grade crossings).

Three, we use information on the opening dates for each Interstate highway segment, up until 1993, from the PR-511 database.[8] The PR-511 database was an administrative database compiled by the Federal Highway Administration for the purposes of collecting statistics about the then-rapidly expanding Interstate network. Thus, these data allow us to construct a time-varying measure of tract proximity to the expanding Interstate highway network.

Four, we digitized several maps of planned freeway routes. Of special interest is the *General Location of National System of Interstate Highways Including All Additional Routes at Urban Areas Designated in September 1955*, popularly known as the "Yellow Book." At the beginning of the Interstate era in 1955, the Bureau of Public Roads (BPR, now the Federal Highway Administration) designated the routes of urban Interstates in a series of maps contained in the Yellow Book. Unlike the earlier 1947 plan, which described only routes *between* cities, the Yellow Book described the general routing of highways *within* each of 100 metropolitan areas.[9] Fifty metropolitan areas have both 1950 tract data and a Yellow Book map.

4 Evidence from building the Interstates

Where and when was opposition to freeway construction concentrated? In this section, we provide evidence that freeway disamenities were disproportionately important in central neighborhoods. In turn, opposition from central neighborhoods affected the allocation of freeways within cities, especially by the late 1960s.

Unfortunately, there is little systematic data on the precise timing and location of opposition to freeway building.[10] Instead, we combine historical narrative with the timing and location of departures from the initial 1955 Yellow Book plans in the routes of completed freeways. Our evidence suggests that the revolts were most successful in diverting or obstructing planned freeways in central neighborhoods, especially by the late 1960s, after policy changes empowered freeway opponents. These patterns are consistent with the prediction that the effect of freeway disamenities were most salient in central neighborhoods.

4.1 The unanticipated freeway revolts and policy responses

By the late 1960s, freeway revolts were widespread. A short-lived survey conducted by the U.S. Department of Transportation (DOT) between October 1967 and June 1968 recorded 123 separate

[8] These data were generously shared by Nate Baum-Snow. We did some further cleaning of these data to ensure accuracy in spatial matching of the PR-511 data to highway segments within metropolitan areas.

[9] 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. The 1947 map showed rural routes that terminated outside metropolitan areas.

[10] The literature includes several excellent case studies, including Mohl (2004) on revolts in Miami and Baltimore. However, outside of the short-lived DOT survey in 1967–1968, there appears to have been few contemporaneous efforts to catalog all of the freeway revolts. Further, contemporaneous media coverage often fails to clearly identify the location and timing of opposition and may have also been selected on neighborhood factors or famous participants.

freeway revolts (Mohl, 2002). 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). Other sources identify over 200 controversial freeway projects across 50 cities (Wikipedia, 2017).

Despite their eventual extent, in the mid-1950s the freeway revolts were largely unanticipated by planners, builders, and even later critics of the Interstate program. Planners had an immature understanding of the negative side effects of cars and limited-access roads in mature cities. For example, 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" (DiMento and Ellis, 2013, p. 19). Engineers at state highway departments and the BPR, who dominated freeway planning in the 1940s and 1950s, had faced little opposition in their experience building the rural sections of the national highway network under the provisions of the Federal-Aid Highway Act of 1944. Finally, even later critics were at first enthusiastic about urban highways. Central-city mayors and officials believed that highways would revitalize struggling downtowns. While they supported the program, few local officials were involving in early freeway building. By the mid-1950s, "[s]tate highway departments [had] consolidated their hold on the urban freeway planning process, eclipsing local planning and public works officials" (p. 100).

A consequence of the unexpected freeway revolts was that highway planners and builders did not systematically select neighborhoods for initial freeway projects in the late 1950s on expected resistance to urban freeways. "[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). Indeed, 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. Which projects were completed first often depended more on the ability of the State highway department to staff up quickly, their experience in right-of-way acquisition or designing (pre-Interstate) freeways, and on the pipeline of previously completed plans (AAHSO, 1965).

Highway policy evolved in response to the spreading freeway revolts. At the beginning of the Interstate era, state and federal highway engineers "had complete control over freeway route locations" (Mohl, 2004). Subsequent highway bills eroded this power. 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. 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 DOT, 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). "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). By 1967, "the freeway debates and protests of the late 1960s begin to erode formerly uncritical acceptance of urban freeways," and federal and state policy had swung decisively in favor of the revolts (DiMento and Ellis, 2013, p. 140).

4.2 The changing allocation of freeways in U.S. cities

The unanticipated, growing revolts and evolving policy environment combined to shape the allocation of freeways within U.S. cities. Increasingly, built freeways diverged from initial plans, with later-programmed freeways less likely to be built according to plan.

> 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 (Mohl, 2004, p. 675)

Figure 2 illustrates this pattern in the Washington metropolitan area. Yellow Book planned routes from 1955 are shown in yellow, and completed freewway routes are colored according to the year first opened to traffic, as recorded in the PR-511 database. Several features are worth noting. One, the realized freeway network is spatially correlated with the 1955 plan. Many completed routes lie close to, or are coincident with, planned routes in the Yellow Book. Two, one completed route, I-66 stretching west from downtown D.C., deviated significantly from the initial plan route. In part, this was due to significant opposition from residents of both Arlington and Falls Church, Virginia; a number of lawsuits delayed construction until the late 1970s. Three, several routes were cancelled altogether in northwest and northeast D.C. There is also historical evidence of significant opposition to new freeways in these areas.

Across all of the cities in our sample, we document departures from the 1955 Yellow Book plan in several ways. First, today, built freeways least resemble the 1955 Yellow Book plan in central neighborhoods. To show this, we use cross-sectional variation among census tracts in proximity to both completed and planned freeways. Figure 3 shows the within-city, tract-level correlation between distance to the nearest completed freeway and distance to the nearest planned freeway.[11] To the extent that the nearest completed freeway is built exactly to plan, this correlation will be maximized at 1. Departures from plan will tend to reduce actual freeway proximity compared with planned freeway proximity for some tracts and increase it for others, leading to correlation coefficients less than 1. We compute correlation coefficients for different groups of census tracts, according to their distance from the city center, indicated by the horizontal axis. Thus, for tracts

[11] These correlation coefficients are computed from coefficients of determination from tract-level regressions of distance to the nearest completed freeway on distance to the nearest planned freeway, conditioned on metropolitan area fixed effects.

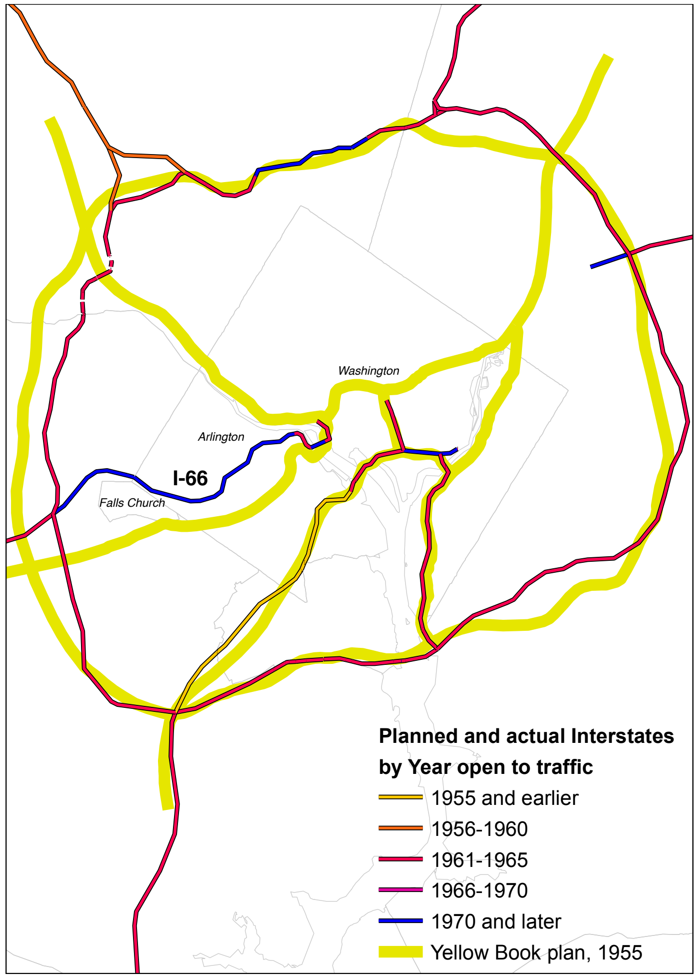
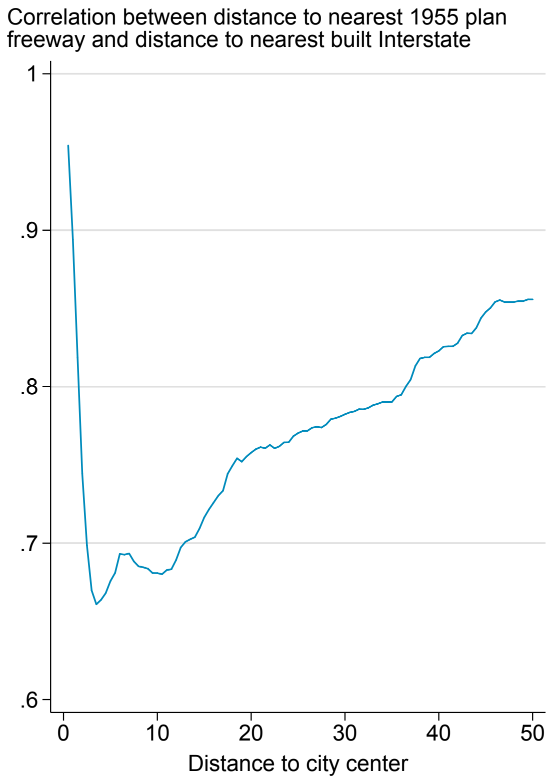


Figure 2: Some highways deviated from initial 1955 plans or were cancelled

Sources: NHPN, FHWA, NHGIS.

within 1 mile of city centers, the correlation between distances to the nearest planned freeway and the nearest completed freeway is 0.95, indicating high spatial correlation between planned and completed freeway networks for the most-central census tracts. However, just outside of downtowns, this correlation falls. Tracts within 10 miles or less of city centers see relatively low correlations between proximities to planned and built freeway networks of less than 0.7, suggesting that built freeways deviated from planned freeways in central neighborhoods just outside of downtown. Still farther, the correlation between planned and built freeways increases, indicating that suburban highways were relatively more likely to be completed according to plan.

This result accords with historical evidence that opposition to urban freeways was mostly concentrated in central neighborhoods, as in the Greenwich Village protests against the Lower Manhattan Expressway proposal. An interesting feature of the data is that outlying correlations are relatively high, despite presumably much more latitude to shift planned freeways to less-developed, "greenfield" sites. (The high correlation within 1 mile of city centers may owe to design principles



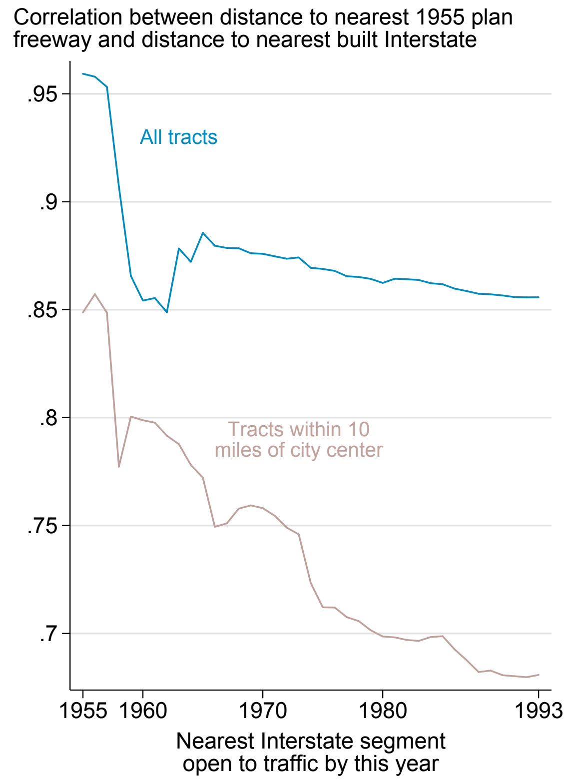


Figure 3: Completed freeway routes least resemble planned freeway routes in central areas

Figure 4: Over time, the correlation between completed and planned freeway routes declined faster and farther in central areas

Sources: NHPN, FHWA, Census.

that had radial highways terminate at a specific point just outside of downtowns—say, next to a seaport or a major arterial.)

Second, over time, the correlation between planned and built freeways declined faster and farther in central neighborhoods. In Figure 4, we conduct a similar exercise as before, except we group tracts according to the year that the nearest built freeway was first open to traffic. Tracts near freeways opened 1955–1957 saw high correlations between proximities to planned and built freeways: over 0.95. However, this correlation fell as new freeways were built along alignments that deviated from planned routes. By 1993, the last year observed in the PR-511 database, the correlation had fallen to 0.86. The decline spatial correlation between planned and built routes was especially sharp in central neighborhoods, again consistent with opposition concentrated downtown. The correlation coefficient fell from 0.85 in 1955–1957 to 0.68 in 1993. This increasing divergence is also consistent with the timeline of policy changes gradually ceding more power to neighborhood interests.

Third, to document the changing importance over time of various factors in determining freeway routes, we construct a annual tract–year panel between 1956 and 1993 and perform the following regression:

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

where $1(f_{gt})$ is an indicator for whether tract g is within one-half kilometer of a freeway in year t.[12] A metropolitan area fixed effect α_{mt} ensures that identification comes from variation within metropolitan areas. A vector of persistent factors (Z_g) includes the natural logarithm of distance to the city center, and indicators for proximity within one-half kilometer to the nearest coastline, river, lake, park, and seaport, and if the average slope of the neighborhood is greater than 15 degrees. We also include a vector of initial tract characteristics measured in 1950 (X_g) such as population density, education, race, and income. These characteristics are standardized within metropolitan area.

The goal of this exercise is to understand the neighborhood factors that predicted selection into the freeway program, and how this predictive relationship evolved over time as the revolts intensified. We perform this regression separately for the planned Yellow Book routes of $t = 1955$ and each year between 1956 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. By 1993, 11 percent of these tracts were eventually treated with highways.

Figure 5 shows the results for four regressors of interest that illustrate evolving selection 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 be interpreted as the increase (or decrease) in probability associated with a one-unit increase in the regressor indicated by the panel title, conditioned on the other regressors.[13] Thus, the panels show the evolution of the correlation between the completed freeway network and (a) proximity to the coast, (b) proximity to a river, (c) proximity to a historical railroad, and (d) hilliness. The first point of each panel 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, the completed network of Interstates was increasingly constructed in coastal neighborhoods. A virtue of coastlines for freeway construction is that they likely eased land assembly issues. Historically, many shorelines tended to be of public or industrial use, easing land acquisition and rights of way for freeways. 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 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.

[12]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.

[13]The appendix contains detailed estimation results, including a logit model which produces similar results.

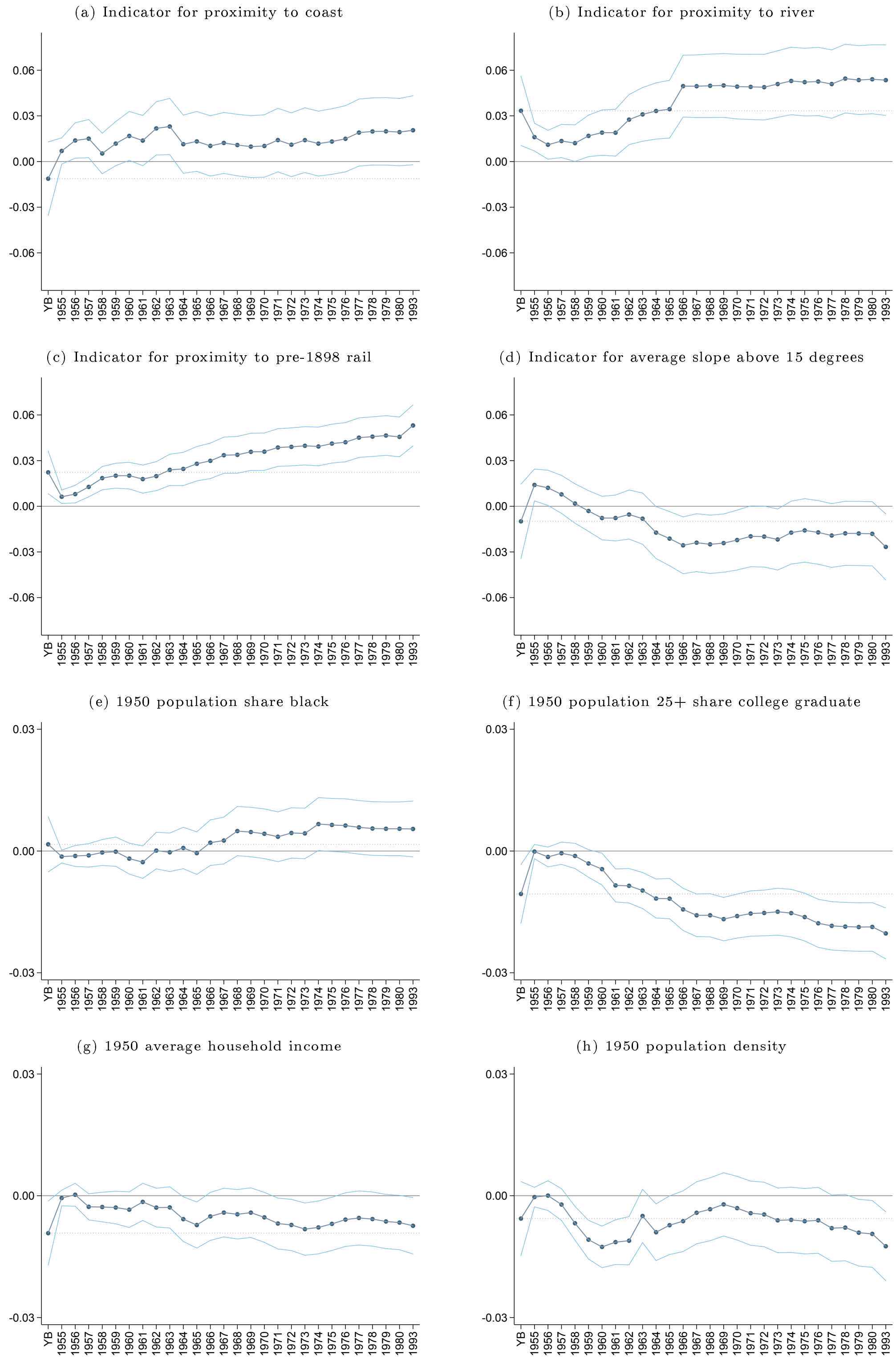


Figure 5: Selection of freeway routes over time by natural, historical, and initial factors

Each panel reports estimates from 28 separate regressions.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) indicator for average slope above 15 degrees. 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, indicators for proximity to coast, river, lake, park, seaport, and average slope, and standardized 1950 population density, black share, college share, and average household income. Standard errors clustered on metropolitan area.Regressions use observations of 15,094 consistent-boundary tracts in 50 metropolitan areas. A negative estimate indicates positive selection on that 1950 tract characteristic for freeway route (i.e., closer to freeways).

> 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.

Panel (b) shows that freeway construction became more likely near rivers through the mid-1960s. Panel (c) shows that built highways increasingly followed historical railroads over time, again suggesting land assembly factors. Finally, panel (d) shows that completed freeways increasingly avoided hilly neighborhoods. These patterns are also consistent with 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 initial social characteristics of neighborhoods predicted freeway selection over time. The four 1950 characteristics are standardized, so the coefficient estimates can be interpreted as the change in probability associated with a one-standard-deviation increase in the neighborhood factor in 1950.

Panel (e) shows that in the Yellow Book, conditioned on natural factors and other 1950 covariates, black neighborhoods were no more likely to be assigned freeways. This continued to be true in the first several years of major Interstate construction. Beginning in the mid-1960s, completed freeways were increasingly located in black neighborhoods (circa 1950), until 1974 or so when the coefficient stabilizes at a level of 0.007. This estimate suggests that a neighborhood with a one-standard deviation increase in the black share in 1950 was 0.7 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 4 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 (f) 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 1.6 percent decline in the probability of of freeway selection. The predicted gap between the least-educated neighborhood and the most-educated neighborhood was about 13 percent.

These dyanmics with respect to educational attainment confirm the predictions of the model of Glaeser and Ponzetto (2017). Interestingly, results shown in panel (g) 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 initial neighborhood income.[14]

Finally, panel (h) shows that densely populated neighborhoods in 1950 were less likely to receive freeways compared with sparsely populated neighborhoods. In regressions reported in the appendix, we also show that among central neighborhoods, selection was even more negative on initial population density. This negative selection on initial population density, especially downtown, is relevant for the discussion of population growth effects in the following section.

In sum, freeway planning and construction evolved in response to the growing revolts of the late 1950s and 1960s. Completed freeways increasingly diverged from initial plans, especially in central neighborhoods, and increasingly favored factors such as coastlines, rivers, and historical rail routes, as well as neighborhoods that were initially more black and less educated. These patterns show that the revolts affected the allocation of freeways within cities, especially near downtowns.

5 Evidence from population growth

Next, we examine the effects of freeways on city structure. To fix ideas, Figure 6 displays a map of 1950–2010 changes in census tract population, in natural logarithms, for the Chicago metropolitan area. 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.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. 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.[15]

Figure 7 summarizes these patterns for all census tracts in all 64 metropolitan areas in our sample.[16] For this analysis, we divided 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.[17]

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

[14] We do not include 1950 housing prices as regressors as the 1950 census tract tables have poor coverage and do not include measures of housing quality or size. See the appendix for details.

[15] Our analysis excludes exurban areas that were not tracted in 1950. A glance at current development patterns outside of the 1950 footprint of the Chicago metropolitan area suggests that population growth was strongest near freeways.

[16] Metropolitan areas are CBSAs as defined in 2010.

[17] Of the 64 metropolitan areas in our sample, 38 have tracts beyond 10 miles.

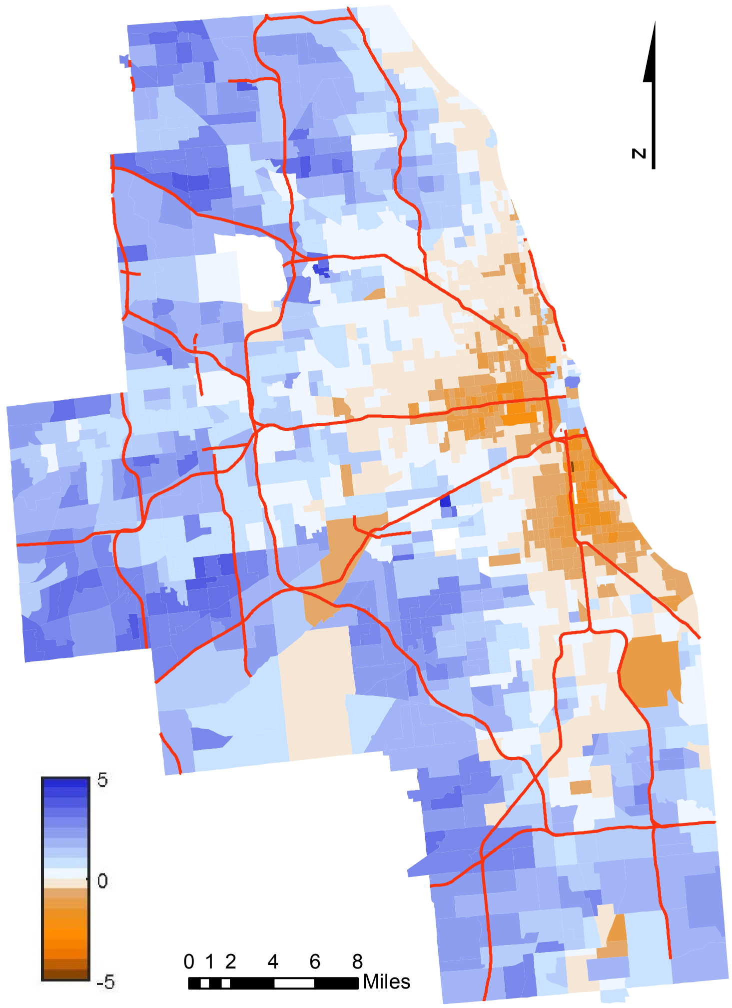
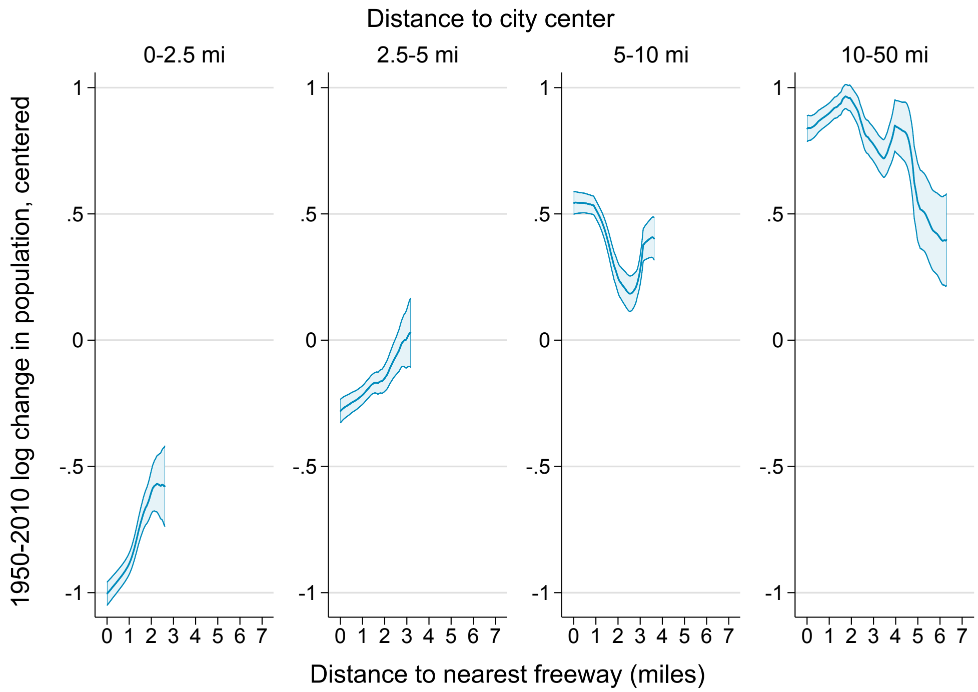


Figure 6: Central neighborhoods declined in population, especially near freeways

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

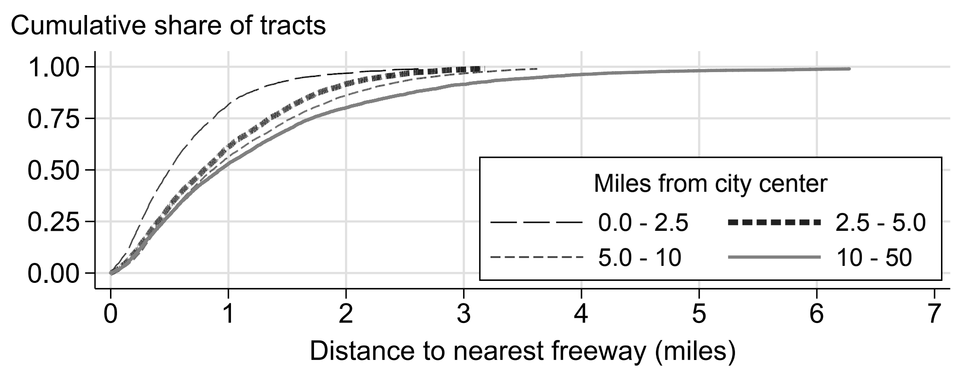


Figure 7: Neighborhoods near freeways declined in central areas and grew in the periphery

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.

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 the predicted effects of freeway disamenities. 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.

Next, we can more formally analyze the patterns shown in Figure 7 with the following regression:

$$\Delta n_{g[m]} = \alpha_m + \beta_1 d_F + Z_g' \gamma + \epsilon_g \tag{2}$$

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.[18] In the simple framework laid out above, 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 (2), where individual tract observations are weighted by the inverse of the number of tracts in the metropolitan aera.[19] 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

[18] A disamenity would be also be consistent with the overall decline in population in the center of the city.

[19] We weight to obtain the average effect across metropolitan areas, instead of the average effect across tracts. We show similar results later without weights.

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 ($\bar{\alpha}_{\cdot}$)	-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 (2). 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.

declines are larger, or population increases are smaller, closer to freeways.) 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. 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.

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 are two possible relevant 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 8) 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.

We also use neighborhood proximity to historical routes as instruments. Identification relies on the premise 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).[20]

We re-digitized the plan and explorer route maps for this project. Previous work by Baum-Snow (2007) and Duranton and Turner (2012) uses cross-metropolitan area variation, so the map-based instruments constructed for those papers contain insufficient spatial detail for our analysis.

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,

[20]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.

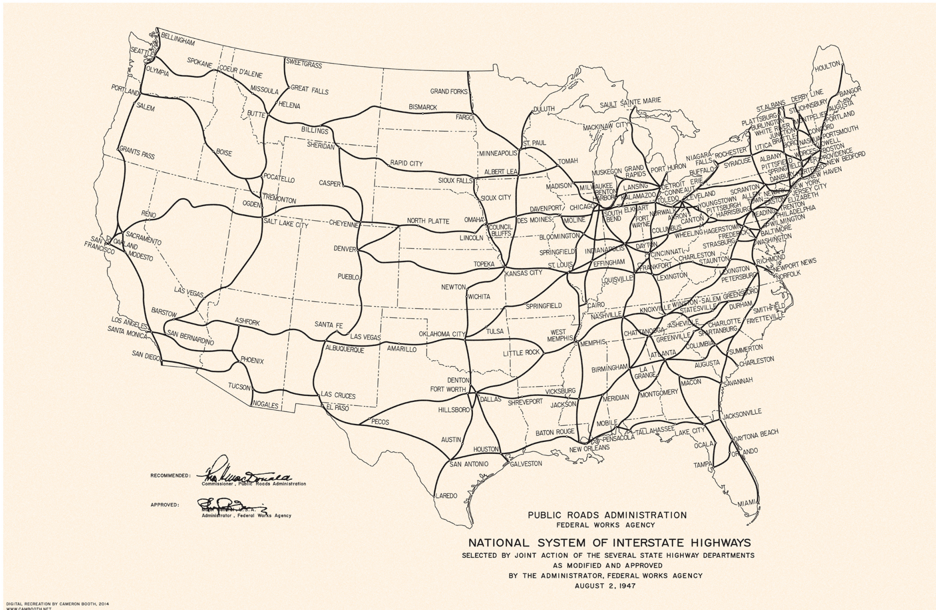


Figure 8: 1947 highway plan

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 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 (some presented previously in section 4) suggests 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. Intuitively, freeway routes that were induced by the instruments ended up plowing through dense, long-developed neighborhoods and had very negative effects. 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

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}—$p < 0.01$.

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.

6 Evidence from job growth

So far, we have inferred freeway disamenities from population and income declines near central-city freeways. While this conclusion is consistent with the basic monocentric city model, 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 model presented in section 9 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. 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. Instead, we use 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.[21] 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.[22]

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; see the data appendix for details. For modern estimates of jobs by census tract, we use

[21] 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.

[22] 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.

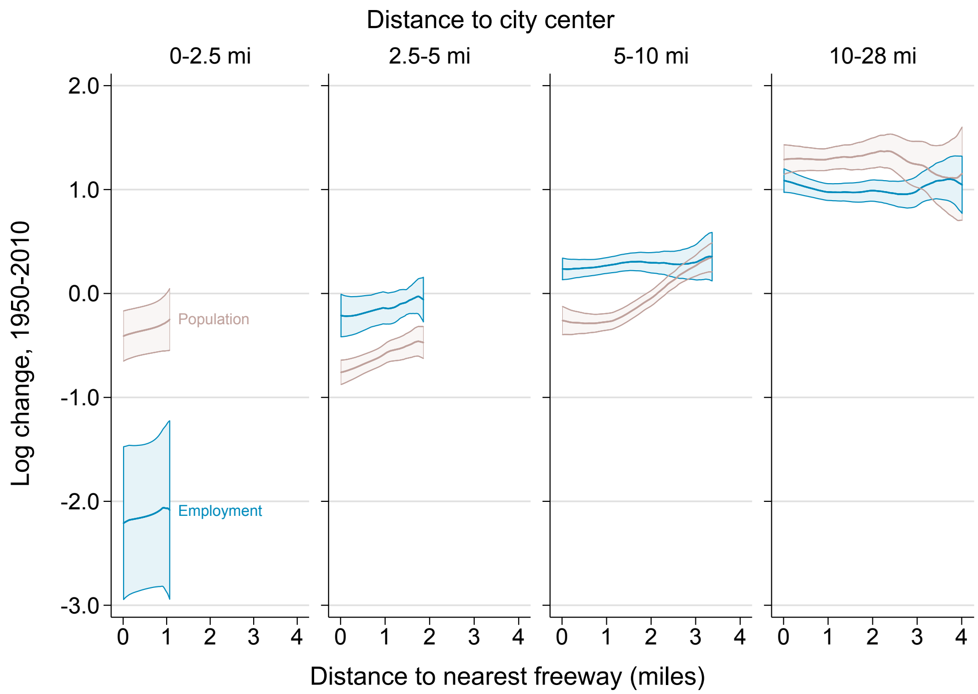


Figure 9: Changes in population and employment in Chicago

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.

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 9 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 9 are worth noting. One, the relationship between population growth and proximity to freeways and the city center corresponds to the patterns observed in Figure 6 and is similar to the pattern observed across all U.S. cities seen in Figure 7. 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

	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 Chicago and 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.

0.40 and 0.41 in Chicago and Detroit, respectively. In sum, Figure 9 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 9, 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.

7 Evidence from changes in 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.[23]

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. Summary statistics can be found in the appendix.[24]

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

[24] Consistent with the decline in transportation costs, the average trip (for all purposes) in the Detroit metropolitan

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 9, except that constant terms are subsumed into fixed effects.

$$\pi_{jkt} = \rho_{jt}\varsigma_{kt}\upsilon_{jk}e^{\nu\tau_{jkt}} \tag{3}$$

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 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 (3) 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 3 using the Poisson psuedo-maximum likelihood (PPML) estimator. Santos Silva and Tenreyro (2006) show that PPML produces consistent estimates and performs well in the

area lengthened from 3.7 to 5.1 miles. However, the median trip increased only from 2.6 to 2.7 miles. Trips by automobile increased from 82 percent to 88 percent. Trips to work (one-way) declined from 24 percent to 20 percent.

presence of zeros.[25]

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.

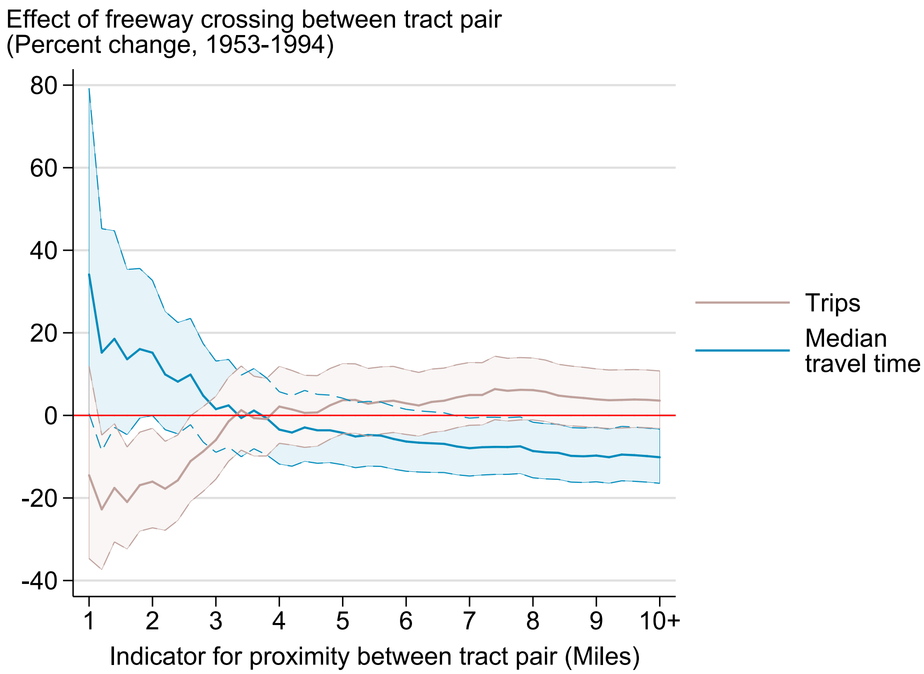


Figure 10: Fewer trips across freeways at short distances and more trips at long distances

Figure 10 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.[26] The estimated parameter 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

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

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

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 10 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}.

8 Other evidence

In Appendix C, we discuss in detail additional evidence that freeway disamenities affected city structure. First, we explore the robustness of our population growth results. The results are robust to (i) controlling for 1950 tract characteristics including the black share of the population, average educational attainment, average household income, and average housing values and rents; (ii) excluding New York and Los Angeles, the two largest metropolitan area; and (iii) ordinary least squares estimation without weights.

We also perform an analysis considering the effects of freeways with respect to access to another type of regional destination. Instead of binning tracts by distance to the city center, we bin tracts by distance to the nearest coastline. Coastlines potentially provide production benefits (i.e., job centers tend to be coastal) and consumption benefits (views, beaches, and moderate temperatures all complement recreational activities). Thus, coastlines tend to be desirable regional destinations. Whether they are destinations for production or consumption reasons, we expect that locations far from the coast benefit more from freeway access, while locations near the coast would experience mostly on the freeway disamenity. We find similar effects compared with our city center results: freeways have large negative effects for neighborhoods close to coastlines, and these negative effects attenuate with distance to the coast.

Using the PR-511 data on freeway completion dates, we also estimate short-run (less than 10 year) effects of freeways on population. These short-run effects are most negative for freeways completed in the 1950s and 1960s. Recall that early freeway routes were somewhat idiosyncratic and likely less selected on neighborhood factors. The strongly negative short-run effects for early freeways is consistent with the strong causal effects estimated with instrumental variables.

We also consider the effects of freeways on the spatial sorting of different income groups. We find that higher incomes sorted away from freeways, and this effect was larger in city centers compared with the suburbs. These results again suggest the importance of freeway disamenities. In the appendix, we discuss identifying the source of these changing sorting patterns in the context of multiple forms of household heterogeneity.

We also estimate the effects of freeways on housing and land prices. Data availability are a challenge for these estimates; reliable measures of housing and land prices for small geographic units around 1950 are scarce. In particular, reported tract-level housing prices from the 1950 Census of Population and Housing suffer from two defects: (i) the universe of houses for which values are measured is owner-occupied units in single-unit structures, which tend to be scarce in downtown neighborhoods, and (ii) there are no measures of housing unit size or quality. That said, we find negative freeway effects on housing prices using these data and a similar concept from the 2006–2010 American Community Survey.

We also perform an analysis using appraised land values for 300 by 300 foot grid cells in the Chicago metropolitan area in 1949 and 1990 (Ahlfeldt and McMillen, 2014).[27] Land values grew slower near freeways in central Chicago; in outlying areas, land values grew faster near freeways.

One surprising element of the results presented in this section is the apparent decline in *firm* demand for freeway-proximate locations in downtowns. First, we note that our estimates of this are imprecise and may not exclude zero effect.[28] One possible factor is strong barrier effects over short distances, as documented by the Detroit travel survey data. We plan to explore this channel more fully using the structural model described in the next section. An interesting piece of corroborating evidence is documented by Floburg (2016). She finds important and dramatic changes in land use in downtown Bridgeport, Connecticut. She digitizes Sanborn maps from 1913 and compared land use to modern map from 2013. All types of private uses declined. Land not covered by buildings increased from 69.5% in 1913 to 80.6% in 2013.

9 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.[29] 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.

[27] These data were generously shared by Gabriel Ahlfeldt.

[28] Structural estimates presented later suggest that the productivity effect of freeways is indistinguishable from zero.

[29] 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).

9.1 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.

9.2 Workers

Workers are homogeneous and have increasing preferences over consumption, c, land, l, and some neighborhood-specific amenity, B_j.[30] 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,

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

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.[31] 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.

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

Individual workers 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,

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

[30] 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).

[31] 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.

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.

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

9.2.1 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.[32] The highway disamenity takes the following form.

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

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

[32]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.

to the highway, and similar forms have been used to study the spatial costs of noise or pollution externalities.[33] We will show that this functional form is consistent with estimated amenities near freeways.

9.3 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.[34] 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.

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

9.4 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 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.[35]

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

[34]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.

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

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.

10 Calibration and estimation of freeway 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.

10.1 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.[36] Chicago provides a good setting given that it exhibits relatively centralized employment, radial commuting patterns, and homogeneous topography. 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 0.95,[37] and for the labor share in production we choose 0.97.[38] The value of κ, which is interpreted as the wage value of time spent commuting is set to be approximately equal to half the wage rate which corresponds to a value of 0.02.[39] Lastly, we set the value of ε to 4, which is approximately in the middle of the range of estimates in the literature.[40]

[36] 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.

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

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

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

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

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.[41] 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 11. 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.

[41] 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.

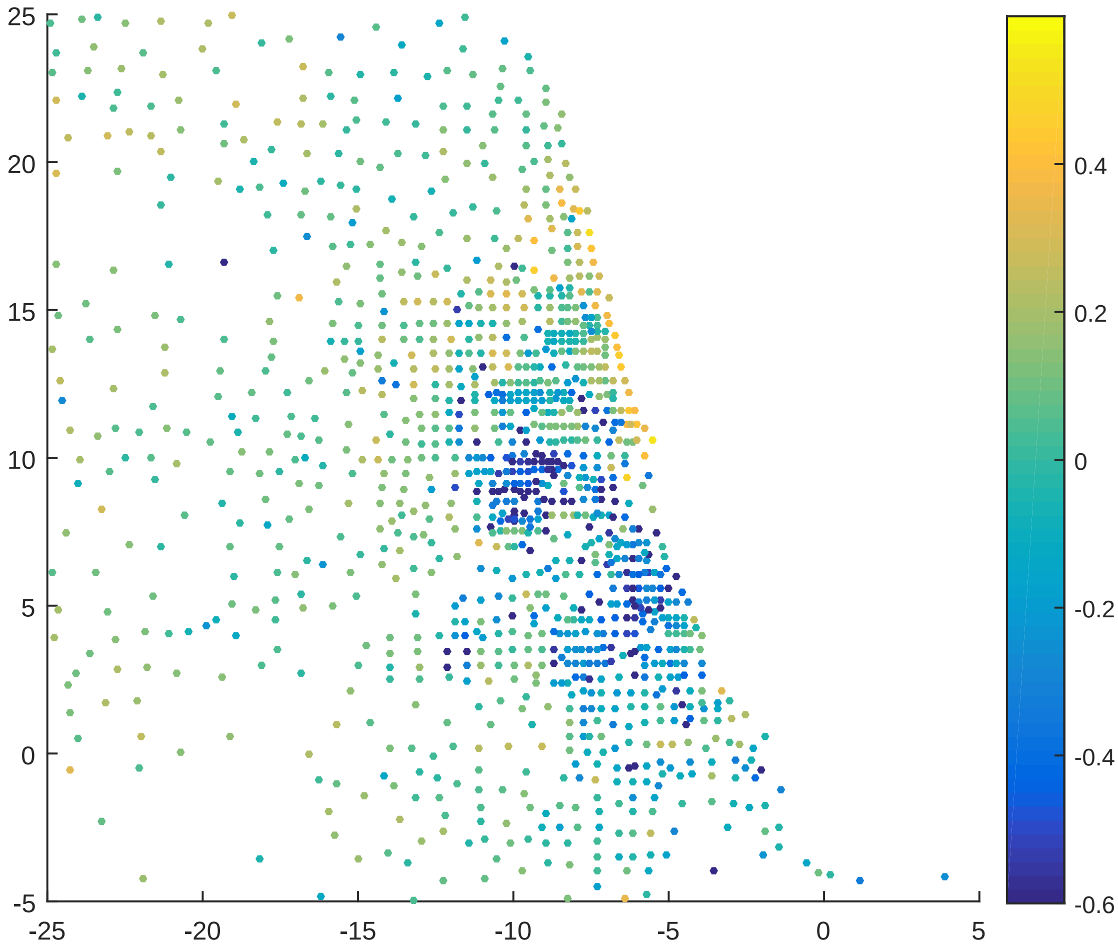


Figure 11: Observed amenities in Chicago

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.

10.2 Estimation of the freeway 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.[42] 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 12 shows a plot of the recovered amenity values and the fitted highway disamenity function for the baseline calibration, where we estimate values of .17 for b_H and 1.3 for η. The interpretation of these parameters is that neighborhoods immediately adjacent to the highway have an amenity reduction of 17 percent, and this effect attenuates by 95 percent at 2.4 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.[43]

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.[44]

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.[45]

11 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

[42] 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.

[43] 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.

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

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

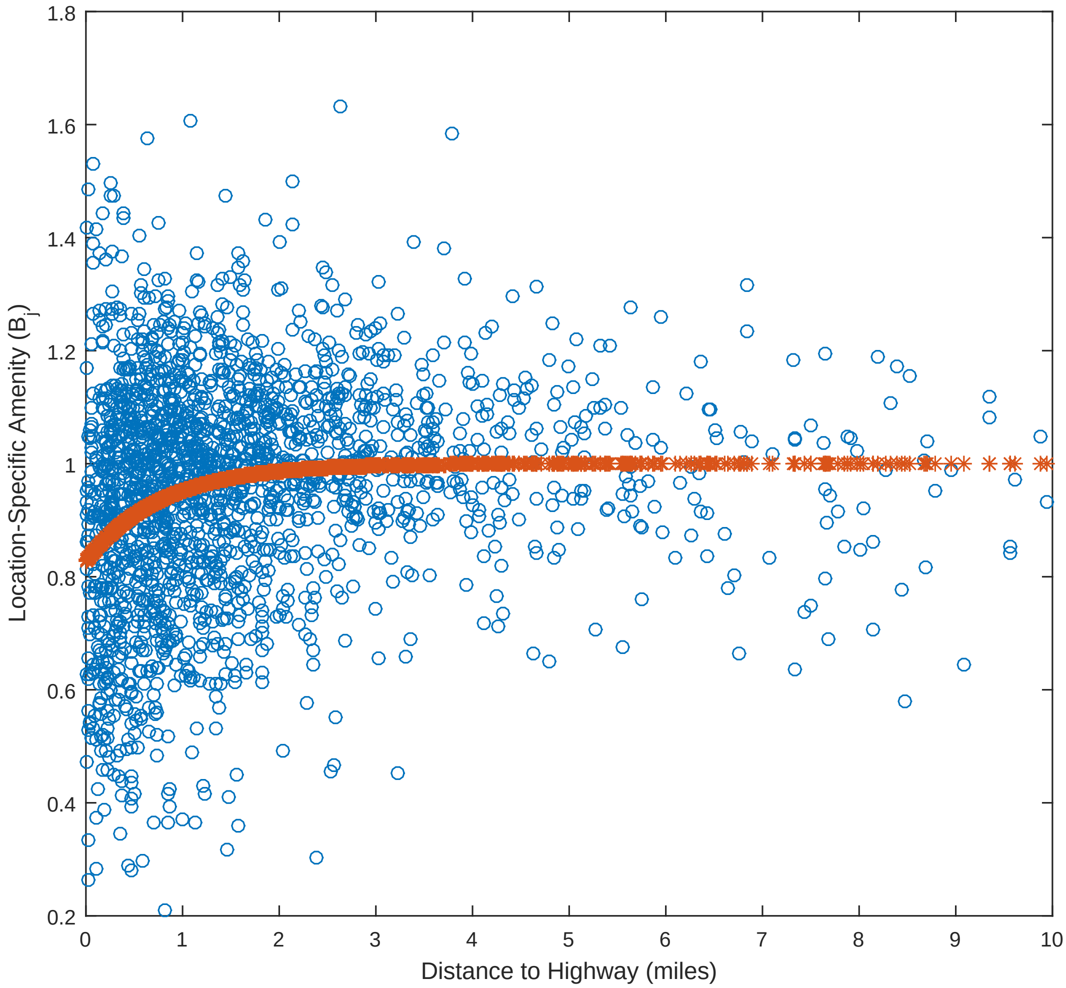


Figure 12: Amenities and proximity to freeways

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	0.950	0.970	4.000	0.172	0.012	1.278	0.132	0.192	0.009	0.505	0.037
0.001	0.950	0.970	4.000	0.170	0.012	1.343	0.143	0.185	0.009	0.523	0.040
0.004	0.950	0.970	4.000	0.177	0.011	1.154	0.113	0.208	0.009	0.470	0.031
0.002	0.930	0.970	4.000	0.161	0.014	1.732	0.219	0.121	0.010	0.530	0.066
0.002	0.970	0.970	4.000	0.189	0.009	0.921	0.078	0.260	0.008	0.477	0.024
0.002	0.950	0.980	4.000	0.174	0.012	1.279	0.131	0.192	0.009	0.507	0.037
0.002	0.950	0.960	4.000	0.171	0.012	1.277	0.133	0.193	0.009	0.503	0.037
0.002	0.950	0.970	2.000	0.299	0.015	0.864	0.076	0.409	0.012	0.432	0.022
0.002	0.950	0.970	6.000	0.121	0.011	1.775	0.227	0.093	0.008	0.558	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.[46] Figure 13 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 5 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 and centralization measures are both calculated as ratios relative to the baseline.

Table 5: Results of simulated mitigation policy

κ	β	α	ϵ	**Utility Change**	**% change <5mi**
0.002	0.950	0.970	4.000	1.051	1.202
0.001	0.950	0.970	4.000	1.048	1.197
0.004	0.950	0.970	4.000	1.057	1.212
0.002	0.930	0.970	4.000	1.036	1.163
0.002	0.970	0.970	4.000	1.074	1.247
0.002	0.950	0.980	4.000	1.051	1.203
0.002	0.950	0.960	4.000	1.050	1.202
0.002	0.950	0.970	2.000	1.128	1.204
0.002	0.950	0.970	6.000	1.026	1.181

This table shows the results of counterfactual experiments where the negative effects of highways are removed, and the economy is simulated again. The utility values represent the ratio of expected utility relative to the initial 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 5 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 20 percent gain in population within five miles of the CBD

[46]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.

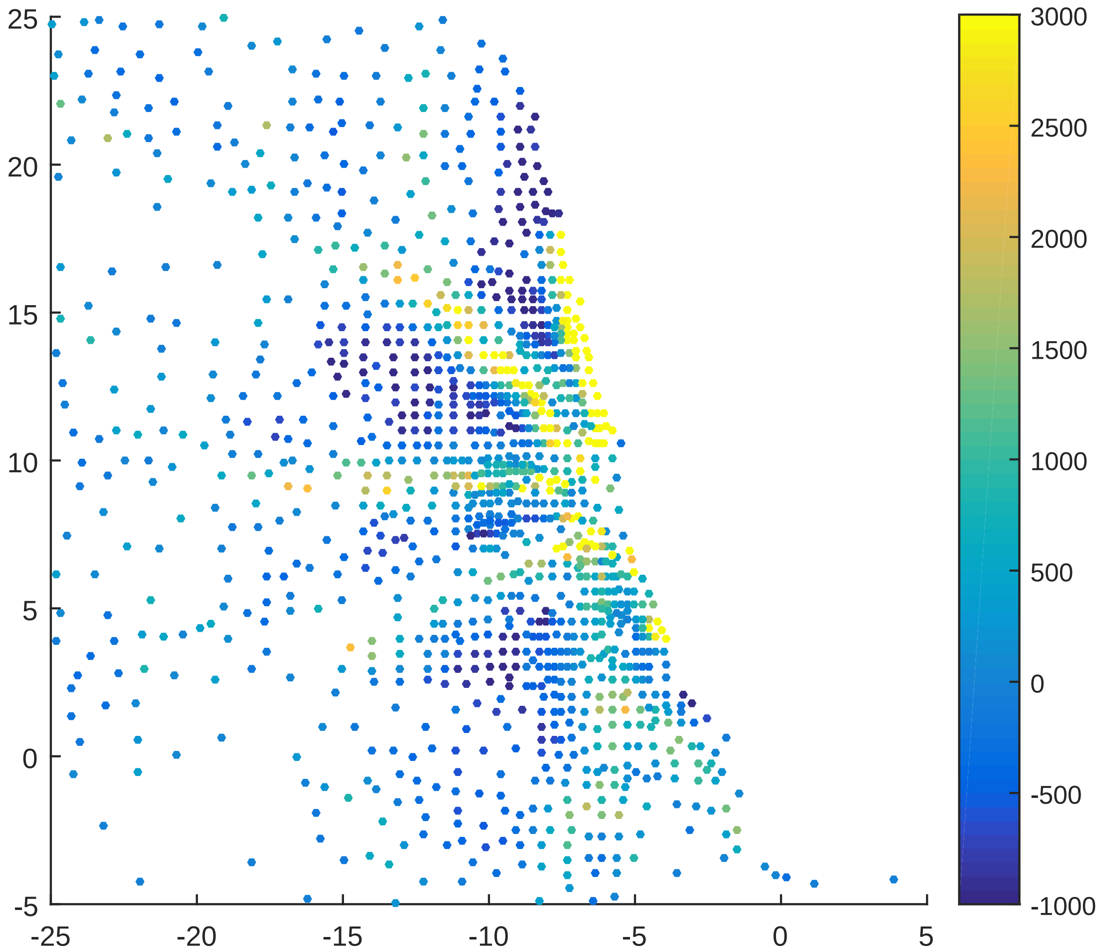


Figure 13: Change in population density after mitigation of freeway disamenities

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.

at the expense of population in outlying areas. The magnitude of utility gains are quite sensitive to calibration choices, ranging from a 2.6 percent gain up to 12.8 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 16.4 percent up to 24.7 percent.

Next we consider the relative importance of mitigation for different locations in the city. This is done in several ways. First, we consider a 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 exercise. The results are shown in Figure 14. 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.

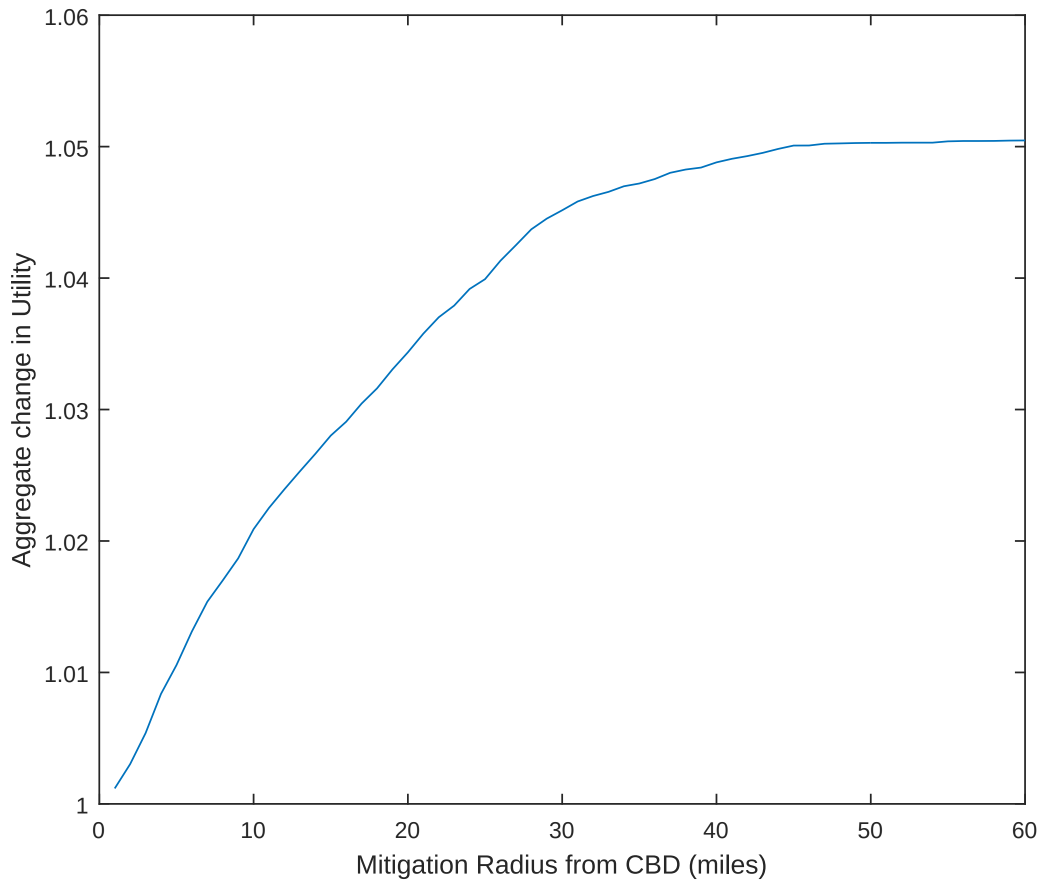


Figure 14: Change in aggregate utility after mitigation of freeway disamenities at different radii

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 15. If the mitigation policy were only applied to neighborhoods within 1 mile of the CBD, population in those neighborhoods would increase nearly 60 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 25 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. More specifically, the concentration of freeways and high population density in central cities could lead to more political will to mitigate the negative effects of freeways than in suburban locations where the negative effects do not effect as large a share of the population.

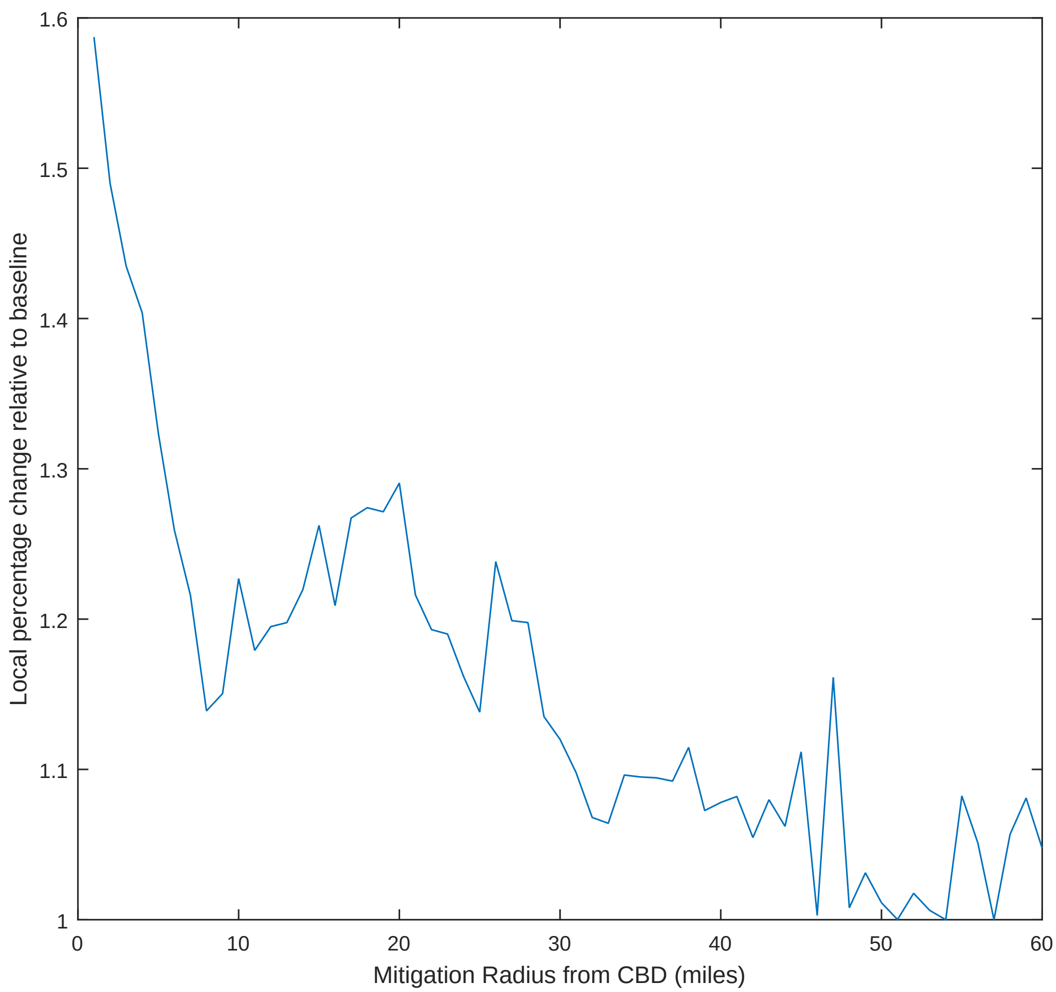


Figure 15: Effect of each location unilaterally mitigating highway disamenity: Percent change in population relative to baseline.

12 Conclusions

To come.

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A Data appendix

A.1 Census tracts and cities

We use data on consistent-boundary neighborhoods spanning many U.S. metropolitan areas from 1950 to 2010 from Lee and Lin (2018). We use census tracts as neighborhoods because tracts are relatively small geographic units and data are available at the tract level, or at a more detailed level, over our sample period. The base data are from Decennial Censuses of Population and Housing between 1950 and 2000 and the American Community Survey between 2006 and 2010[47]. These data were previously constructed in Lee and Lin (2018). The online appendix to Lee and Lin (2018) contains additional details about data construction.

Since boundaries change from one decade to the next, these data are normalized historical data to 2010 census tract boundaries. For example, average household income in 1950 for each 2010 tract is computed by weighting the average household incomes repoted for overlapping 1950 census tracts, where the weights are determined by overlapping land area.[48]

We assign each neighborhood to one of 64 metropolitan areas, using the Office of Management and Budget's definitions of core-based statistical areas (CBSAs) from December 2009. We refer to each metropolitan area as a "city."

[Table: List of metropolitan areas, number of consistent-boundary tracts, available Yellow Book map]

For each neighborhood we measure its distance to the principal city's center, a fixed point in space. We use definitions by Fee and Hartley (2013), who identify the latitude and longitude of city centers by taking the spatial centroid of the group of census tracts listed in the 1982 Census of Retail Trade for the central city of the metropolitan area. Metropolitan areas not in the 1982 Census of Retail Trade use the latitude and longitude for central cities using ArcGIS's 10.0 North American Geocoding Service.

The neighborhood data from Lee and Lin (2018) also contain measures of natural amenities. Spatial data on water features—coastlines, lakes, and rivers—is from the National Oceanic and Atmospheric Administration's (2012) Coastal Geospatial Data Project. These data consist of high-resolution maps covering (i) coastlines (including those of the Atlantic, Pacific, Gulf of Mexico, and Great Lakes), (ii) other lakes, and (iii) major rivers. Average slope for each tract is computed using the 90-meter resolution elevation map included in the Esri 8 package and the ArcGIS slope geoprocessing and zonal statistics tools.

[Table: Summary statistics]

A.2 Roads

For this project, we match each consistent-boundary tract to the nearest present-day freeway from the National Highway Planning Network 14.05 (2014), a database of line features representing highways in the United States. From the NHPN we select only limited access roads, i.e., highway segments that offer "full access control," or all access to the highway is via grade-separate interchanges. Interstate highway segments (except for some that pre-date the Interstate designation)

[47] The ACS data represent 5-year averages of residents and houses located in each tract. For convenience, we refer to these data as coming from the year 2010.

[48] For census data from 1970 and later, we use the population of overlapping census blocks as weights, instead of of overlapping land area.

Table 6: Metropolitan areas with 1950 census tract data or included in the 1955 Yellow Book

State	Metropolitan area	Both	Tract	YB
AL	Birmingham	✓	✓	✓
	Gadsden			✓
	Montgomery			✓
	Tuscaloosa			✓
AR	Fort Smith			✓
	Little Rock			✓
AZ	Phoenix			✓
	Tuscon			✓
CA	Los Angeles	✓	✓	✓
	Oakland	✓	✓	✓
	Sacramento		✓	
	San Diego		✓	
	San Francisco	✓	✓	✓
	San Jose	✓	✓	✓
CO	Denver	✓	✓	✓
CT	Bridgeport		✓	
	Hartford	✓	✓	✓
	New Haven		✓	
DC	Washington	✓	✓	✓
FL	Miami	✓	✓	✓
	Pensacola			✓
	St. Petersburg			✓
	Tampa			✓
GA	Atlanta	✓	✓	✓
	Macon			✓
IA	Davenport-Moline			✓
	Des Moines			✓
ID	Pocatello			✓
IL	Chicago	✓	✓	✓
IN	Gary	✓	✓	✓
	Indianapolis	✓	✓	✓
	Peoria			✓
KS	Topeka			✓
	Wichita	✓	✓	✓
KY	Louisville	✓	✓	✓
LA	Baton Rouge			✓
	Lake Charles			✓
	Monroe			✓
	New Orleans	✓	✓	✓
	Shreveport			✓
MA	Boston	✓	✓	✓
	Springfield	✓	✓	✓
	Worcester			✓
MD	Baltimore	✓	✓	✓
ME	Bangor			✓
	Biddeford-Saco			✓
	Portland			✓
MI	Battle Creek			✓
	Detroit	✓	✓	✓
	Flint	✓	✓	✓
	Grand Rapids			✓
	Kalamazoo		✓	
	Lansing			✓
	Saginaw			✓
	Warren	✓	✓	✓
MN	Duluth		✓	
	Minneapolis	✓	✓	✓
MO	Kansas City	✓	✓	✓
	St. Joseph			✓
	St. Louis	✓	✓	✓
MS	Jackson			✓
MT	Butte			✓
	Great Falls			✓
NC	Durham		✓	
	Greensboro		✓	
NE	Lincoln			✓
	Omaha	✓	✓	✓
NH	Manchester			✓
NJ	Camden	✓	✓	✓
	Trenton	✓	✓	✓
NY	Albany			✓
	Buffalo	✓	✓	✓
	Kingston			✓
	New York	✓	✓	✓
	Rochester	✓	✓	✓
	Schnectady			✓
	Syracuse	✓	✓	✓
	Utica	✓	✓	✓
OH	Akron		✓	
	Cincinnati	✓	✓	✓
	Cleveland	✓	✓	✓
	Columbus	✓	✓	✓
	Dayton		✓	
	Toledo	✓	✓	✓
OK	Oklahoma City	✓	✓	✓
	Tulsa			✓
OR	Eugene			✓
	Portland	✓	✓	✓
	Salem			✓
PA	Allentown-Bethlehem			✓
	Erie			✓
	Harrisburg			✓
	Philadelphia	✓	✓	✓
	Pittsburgh	✓	✓	✓
	Reading			✓
RI	Providence	✓	✓	✓
SC	Columbia			✓
	Greenville			✓
	Spartanburg			✓
SD	Rapid City			✓
	Sioux Falls			✓
TN	Chattanooga	✓	✓	✓
	Knoxville			✓
	Memphis	✓	✓	✓
	Nashville	✓	✓	✓
TX	Austin		✓	
	Dallas	✓	✓	✓
	Fort Worth	✓	✓	✓
	Houston	✓	✓	✓
	San Antonio			✓
VA	Bristol			✓
	Norfolk			✓
	Richmond	✓	✓	✓
	Roanoke			✓
VT	Burlington			✓
WA	Seattle	✓	✓	✓
	Spokane		✓	
	Tacoma		✓	
WI	Milwaukee	✓	✓	✓
WV	Wheeling			✓

are a subset of limited access roads; some limited access roads were financed by non-federal funds only.

A.3 Road opening dates

We match each urban freeway segment to the PR-511 database, an administrative database that contains information about when each segment first opened to traffic.

The Federal Highway Administration kept track of the status of the Interstate System during its active construction years on Form 511. It was a 3×6-foot form with a horizontal line diagram respresenting the Interstate route in the center of the page. The line was marked with cross features such as interchanges, rivers, roads, and railroads. The status was entered in lines above the diagram as each segment (a specified milepost to milepost, such as a river to a main crossroad, but not necessarily the same mileposts seen today) moved from preliminary engineering to design to right-of-way acquisition to construction to open but not to full standards to open-to-full standards (the final status).

The PR-511 data was also compiled on a mainframe computer program. The final version of that database was printed out in 1993 and is the base for our data. (Unfortunately, the original electronic version of this database has been lost or destroyed.) This form notes that State, the route, the milepost-to-milepost segment, and dates for each stage of planning to completion.

The PR-511 database has been used in previous studies, including Chandra and Thompson (2000), Baum-Snow (2007), Michaels (2008), and Nall (2015). We start with the version digitzed by Baum-Snow (2007). Baum-Snow (2007) used line features representing highways that were split into equal length segments of 1 miles each. Then, these segments were matched with the PR-511 database to determine the opening date for each highway route segment. We performed some additional cleaning of these data to achieve better matching of the PR-511 database to route segments at census tract resolution.

[Table validating PR-511 data by comparing aggregates to published statistics?]

A.4 Plan and historical routes

We digitized several maps of planned or historical transportation routes.

One, we digitized the 1947 Interstate plan. The Federal-Aid Highway Act of 1944 had called for the designation of a National System of Interstate Highways, to include up to 40,000 miles. This is the map used in Baum-Snow (2007) as an instrument for completed Interstates. States were asked to submit proposals for their portion of the Interstate highway system. They then negotiated with the Bureau of Public Roads and the Department of Defense over routing and mileage. In 1947, the BPR announced the selection of the first 37,000 miles. Baum-Snow's coding of these planned Interstate routes required only metropolitan-level variation, so was unsuitable for our analysis. Instead, we digitized the 1947 plan map.

Other previous studies using the 1947 Interstate plan as an instrument for completed highways include Chandra and Thompson (2000), Michaels (2008), and Duranton and Turner (2012).

Because the 1947 plan map was drawn at a national scale, there is little detail inside metropolitan areas. In fact, metropolitan areas are represented as open circles. This is a virtue for our instrumental variables analysis, since information about neighborhood factors did not enter into the routing of the 1947 plan map highways. (The 1947 highway plan makes no mention of transportation within cities or future development.) On the other hand, the size of the open circles and the poor resolution of the 1947 plan map mean that in practice it is challenging to precisely assign the routes of plan highways according to the 1947 map. To the extent possible, we use the center of the drawn lines of the 1947 map. When drawn lines terminate at open circles, we extend these lines to principal city centers from Fee and Hartley (2013). We do this to ensure relevant variation in proximity to plan routes—without these extensions, all 1947 plan routes would terminate at the edge of the metropolitan area. In addition, Interstate design principles enshrined later (e.g., AASHO, 1957) codified the radial structure of U.S. city highway networks seen today, where multiple rays converge to locations just outside of central business districts.

Two, we digitized the *General Location of National System of Interstate highways including All Additional Routes at Urban Areas Designated in September 1955*, popular known as the "Yellow Book." In 1955, the Bureau of Public Roads designated the remaining mileage of Interstates authorized by the 1947 Interstate plan. 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. As before, state highway departments submitted proposals to the BPR and then negotiated over routing and mileage for the 1955 Yellow Book routes. In general, they followed a radial-concentric ring pattern codified in *Interregional Highways* (1944), a Congressional report that outlined basic highway designs, adapted to topographical and land-use characteristics of each metropolitan area (Ellis, 2001).

Three, we digitized routes of exploration from the 16th to the 19th century from the National Atlas (1970). These were first used as instruments for actual highways by Duranton and Turner (2012). Again, they used variation across metropolitan areas; we digitized these maps so that the data were suitable for analysis at the scale of census tracts.

Four, we use historical rail routes from Atack (2016). Following Duranton and Turner, we select rail routes in operation by 1898 from the Atack (1898) database.

A.5 Chicago land prices

Ahlfeldt and McMillen (2014) digitized various editions of *Olcott's Blue Books of Chicago*. These volumes provide land value estimates for detailed geographic units in the form of printed maps. Often, different estimates are reported for different sides of the same street, different segments of the same block, and for corner lots. They coded these data for 330×330 foot grid cells. Gabriel Ahlfeldt graciously shared the 1949 and 1990 data with us. These data were also used in Ahlfeldt and McMillen (2014) and McMillen (2015).

A.6 Chicago and Detroit travel surveys

For this study, we used 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 aggregate 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 (a geographic area smaller than our sample area, which is all 1950 tracts in the metropolitan area) and 1,324 thousand jobs in Cook and DuPage counties (larger than our sample area)[49]. Unlike the travel survey, the Census of Business notably lacked coverage 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.

Table 7: Comparison of 1950s employment data for the Chicago metropolitan area

	CATS jobs by zone, 1955-7[a]	CATS person-trips to work, '56	Census of Business, 1954			Census of Population, 1950
			2-county[d]	5-county[e]	City	2-county
Construction	39.2[c]	.	.	.	.	.
Manufacturing	827.6	713	772.1	843.5	615.7	.
Transp., comm., util.	.	173	.	.	.	.
Wholesale trade	125.0[c]	134	143.5	148.0	131.4	.
Retail trade	131.2[c]	327	280.6	304.5	223.5	.
Private services	.	326	.	.	.	.
... Finance	88.5[c]	.	.	.	.	.
... Selected services[b]	.	.	128.0	134.7	111.8	.
Public administration	.	216	.	.	.	.
Total	1,211.5	1,500	1,324.2	1,430.7	1,082.4	2,036.4

A period (".") indicates employment for the sector indicated by the row title is not reported by the source indicated by the column title. [a]—Average total covered employment over 1955-1957, reported by CATS zone. CATS zones cover nearly all of Cook County; approximately the eastern half of DuPage County, and very small portions of Lake and Will Counties. [b]—Selected services covered by the 1954 Census of Business are: Personal services; Business services; Auto repair services; Miscellaneous repair services; Amusement and recreation Services; Hotels and tourism. [c]—Employment by CATS zone for these sectors reported for only 16 central zones (out of 44); other zones censored for low coverage. [d]—Cook and DuPage Counties. [e]—Cook, DuPage, Kane, Lake, and Will 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)[50]. The 1950 Census of Population also reported 983 thousand jobs reported by residents of Wayne county.

Figure 16 shows the emprical cumulative distribution of trip length in miles in 1953 and 1994.

[49]The 1956 Chicago travel survey sampled an area consisting of nearly all of Cook County, the eastern half of DuPage county, and very small portions of Will and Lake (IL) counties.

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

Table 8: Comparison of 1950s employment data for the Detroit metropolitan area

	DMATS, 1953	Census of Business, 1954 Wayne co.	Census of Business, 1954 Detroit metro	C. of Pop., 1950 Wayne co.
Construction	42.8	.	.	.
Manufacturing	527.4	445.5	538.2	.
Transp., comm., util.	61.9	.	.	.
Wholesale trade	27.3	46.3	48.5	.
Retail trade	124.3	138.6	171.0	.
Selected services	.	51.0	58.1	.
... FIRE	33.4	.	.	.
... Personal services	64.0	.	.	.
... Professional services	61.8	.	.	.
Public administration	40.0	.	.	.
Total	982.9	681.4	815.8	983.0

A period (".") indicates employment for the sector indicated by the row title is not reported by the source indicated by the column title. [a]— Selected services covered by the 1954 Census of Business are: Personal services; Business services; Auto repair services; Miscellaneous repair services; Amusement and recreation Services; Hotels and tourism.

Table 9: Summary statistics, 1953 and 1994 DMATS

	1953	1994 Full sample	1994 1950 tracts
Sample			
Households	36,226	6,653	4,265
Persons	75,395	14,036	8,282
Trips	250,453	58,733	30,940
Trip distance, miles			
μ (σ)	3.7 (3.5)	5.1 (13.0)	3.8 (4.3)
p50	2.6	2.7	2.2
(p25, p75)	(1.0, 5.4)	(1.0, 6.5)	(0.8, 5.1)
Origin distance to city center, miles			
	8.7 (4.9)	19.7 (14.1)	12.0 (4.8)
Mode			
Car	0.82	0.88	0.87
Transit	0.16	0.02	0.02
Walk	NA	0.06	0.08
Purpose			
to work	0.24	0.20	0.19
to shopping	0.08	0.09	0.09

Table 9 shows summary statistics for the 1953 and 1994 Detroit surveys. (The last column shows statistics for only households living in the 1950 footprint of the city.) 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.) For households in the 1950 footprint of the city, average trip length increased by 0.1 miles and the median trip decreased by 0.4 miles. 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.[51]

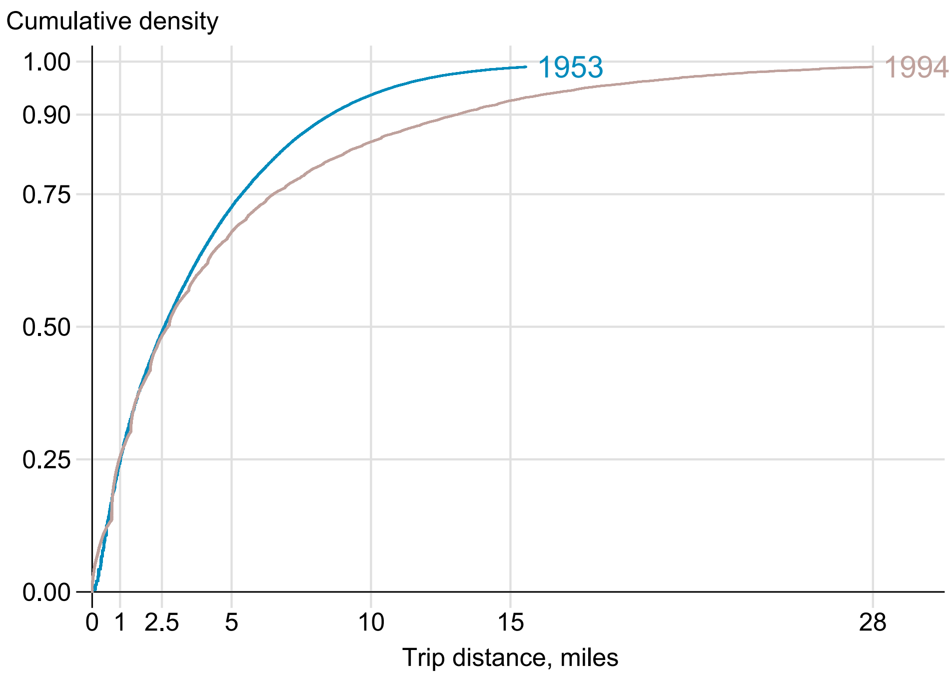

Figure 16: Cumulative distribution of trip length in 1953 and 1994

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

A.7 Chicago commuting flows in 2000

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

A.8 Works cited

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B Selection over time

[Insert regression table here]

C Other evidence

Robustness of population results To illustrate the robustness of the results so far, Figure 17 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.

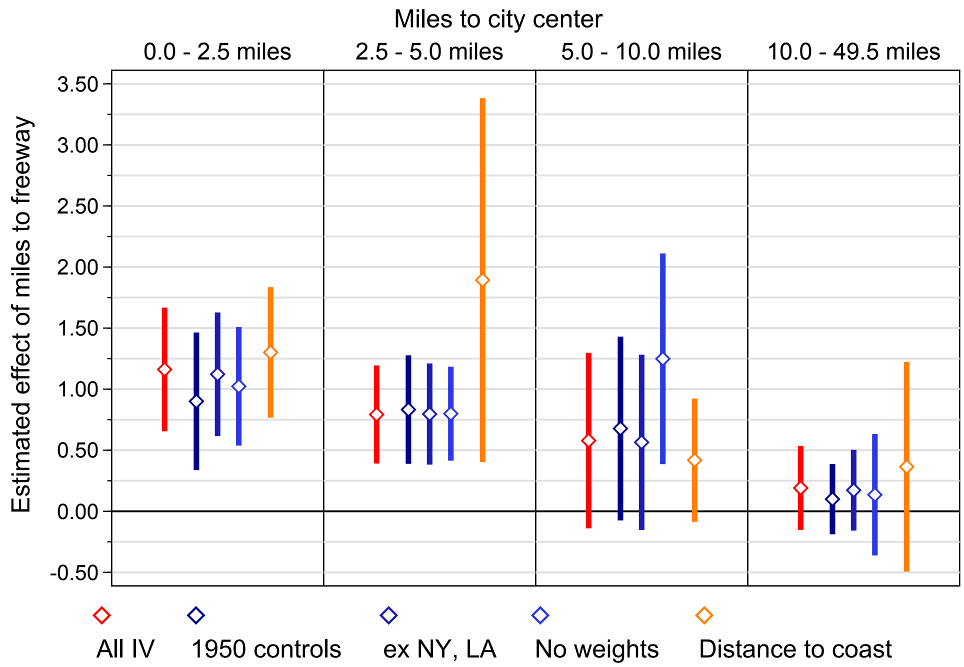

Figure 17: Robustness of freeway effects on population

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.

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 17 reports coefficient estimates where the sample of neighborhoods is conditioned on distance to the nearest coastline instead of distance to the city center.[52] Coastlines potentially provide production benefits (i.e., job centers tend to be coastal) and consumption benefits (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.

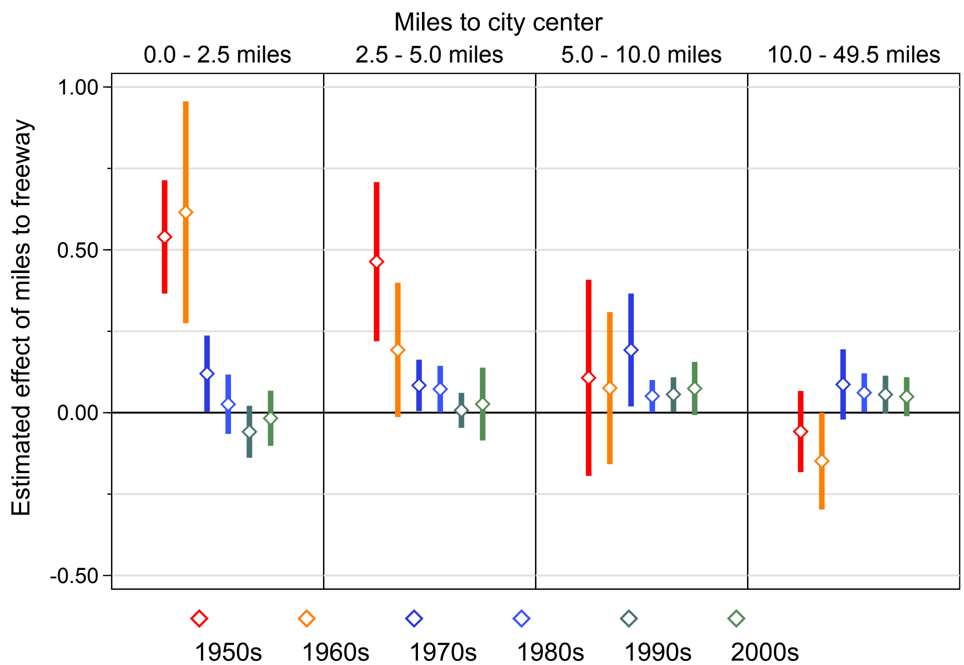

Figure 18: Freeway effects on population largest in the 1950s and 1960s

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

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

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 to the extent that adjustment may be slow.

The negative effects of freeway construction in central cities were most pronounced between 1950 and 1970. Figure 18 shows these estimates. These estimates may provide additional validation of the instrumental variables estimates of the causal effect of freeways on downtown neighborhoods, since the historical and statistical evidence presented in the previous section suggests that early highway construction was less selected on neighborhood factors owing to the surprise of the revolts.

C.1 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 estimation results shown in Figure 19, 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 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 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 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 incomethen this would result in sorting away from freeways everywhere. In addition, differences in relative benefits of highways through the net wage function 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 (2018).

C.2 Housing and land values

Next, we estimate the effects of freeways on housing and land prices. Land values would seem to be the most direct test of freeway disamenities. However, reliable measures of land value are difficult

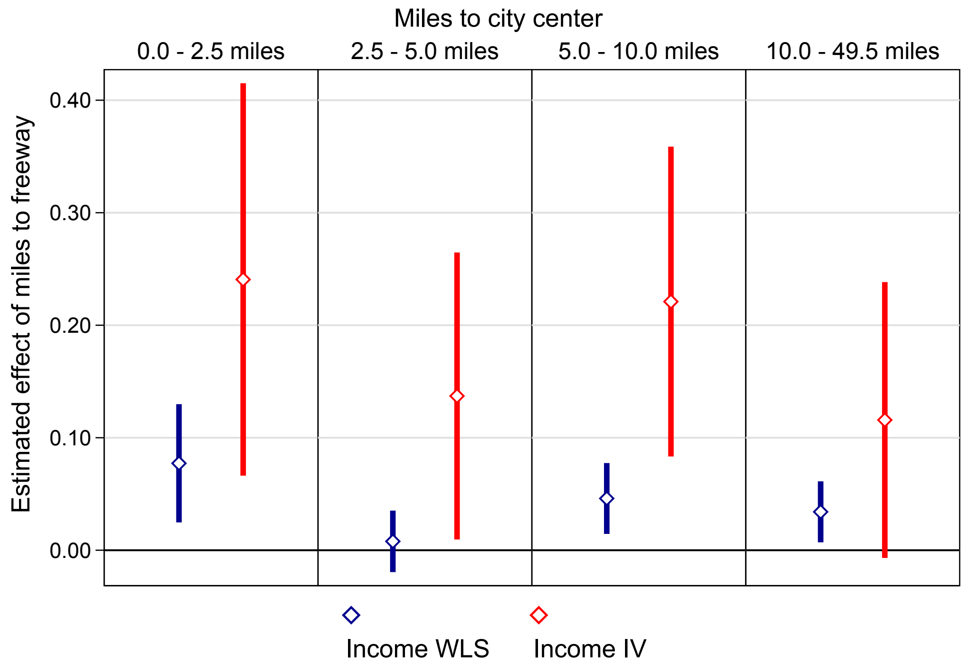

Figure 19: Robustness of estimated effect of freeway proximity on population change

Each point 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.

to obtain for a large universe of small geographic units in the 1950s. While housing prices are available in the Census of Population and Housing, unobserved heterogeneity in housing quality presents another challenge for inference. Unfortunately, the 1950 housing tables for census tracts only report home values for owner-occupied housing units in single-unit structures. Therefore, reported home values represent a selected sample, especially in central neighborhoods where both ownner-occupiers and single-unit structures are less common. There are also no measures of housing unit size or quality in the 1950 tract data by which we might adjust reported home values.[53]

Those important caveats aside, we estimate the effect of highways on housing prices for owner-occupied housing units in single-unit structures (having obtained measures of the same concept from the 5-year American Community Survey estimates for 2006–2010.) These estimates are shown in Figure 20. Conditioned on not being able to measure housing quality, the point estimates suggest that housing prices increased faster away from highways. This is perhaps with disamenities from highways, although the estimates lack the attenuation pattern with proximity to the city center seen for other outcomes.

To provide further evidence in light of the limitations of the Census house-price data, we turn to a measure of land values available for Chicago. We obtained appraised land values for 300×300 foot grid cells (n.b. not tracts) from *Olcott's Blue Books* in 1949 and 1990 from a database digitized

[53]The sole exception is a measure of crowdedness, the count of the number of housing units for which the ratio of occupants to rooms exceeds 1. Unfortunately, other census tract tables only report the average number of occupants per housing unit, regardless of size, and units by number of rooms are reported in relatively coarse categories.

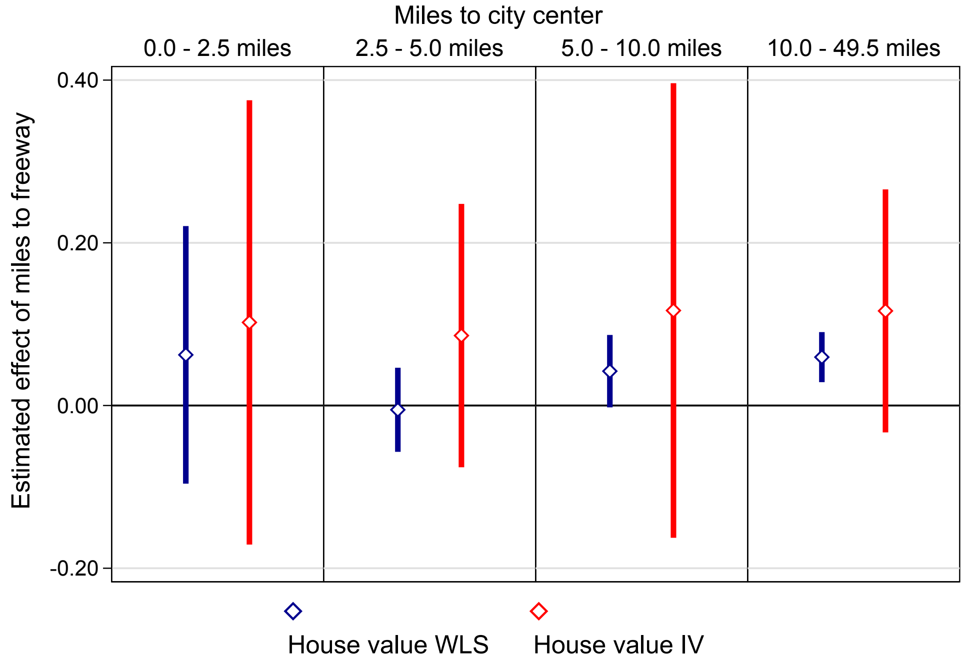

Figure 20: House prices increased more farther from freeways

Each point is an estimate from a separate fixed-effects regressions of the logarithm of the 1950–2010 change in consistent-tract average house price for owner-occupied housing units in single-unit structures only 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.

by Ahlfeldt and McMillen (2014, 2015, 2017). The smoothed data are shown in Figure 21. Here the patterns are more clear compared with Census housing prices. In the core areas of Chicago, tracts closest to freeways saw slower land value appreciation compared with tracts farther away. In the peripheral areas of Chicago, tracts closest to freeways saw faster land value appreciation compard with tracts farther away. These patterns seem consistent with reduced household and firm demand for land near highways in downtown Chicago.

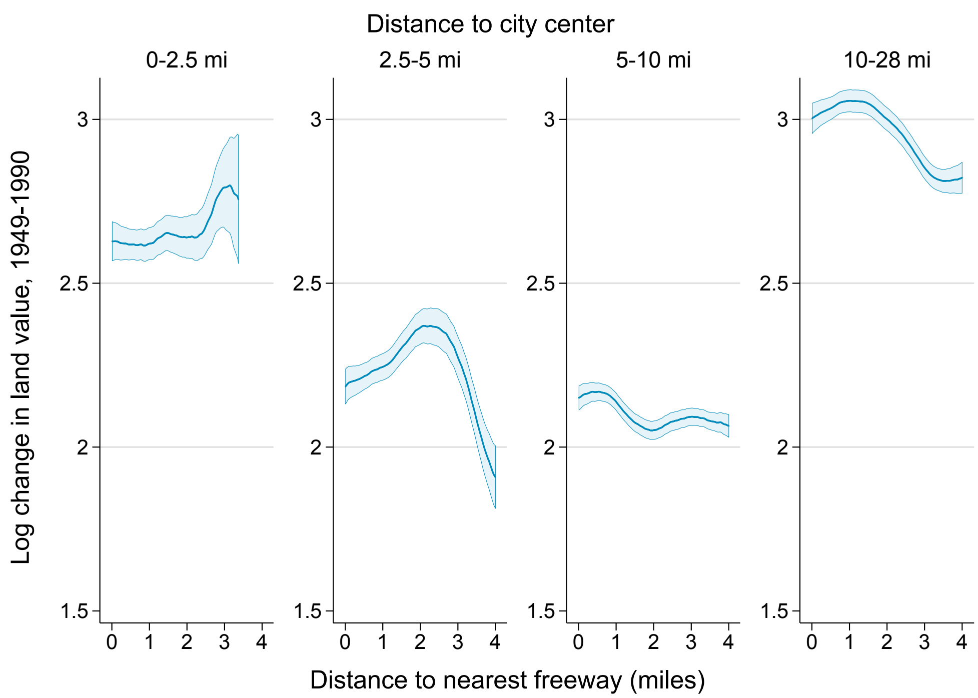

Figure 21: Land value growth in Chicago, 1949–1990

Lines show kernel-weighted local polynomial smooths of the 1949–1990 change in the natural logarithm of appraised land value in the Chicago metropolitan area. Smooths use Epanechnikov kernel with bandwidth XYZ and local-mean smoothing. Shaded areas indicate 95 percent confidence intervals.