Expecting an Expressway

Jeffrey Brinkman Jeffrey Lin Kyle Mangum*

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Abstract

We provide theory and evidence on the role of self-fulfilling expectations in determining urban spatial structure. In U.S. central cities, there was near certainty in the mid-1950s that planned urban highway segments would reduce neighborhood quality of life, as Interstate builders enjoyed widespread support and faced few constraints. But unanticipated federal and state reforms led to the permanent cancellation of some highway projects after 1973. Planned—but never constructed—urban Interstate segments caused neighborhood declines through 1970, and these declines persisted for decades afterwards, despite plan cancellation. These results are consistent with forward-looking behavior and strong economies of density in residential location choice.

Keywords: self-fulfilling expectations, history dependence, multiple equilibria
JEL classification: D84, N92, O18, R14

*E-mail: jeffrey.brinkman@phil.frb.org, jeff.lin@phil.frb.org, kyle.mangum@phil.frb.org.
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1 Introduction

What determines urban spatial structure? An intriguing hypothesis is that self-fulfilling expectations can play a decisive role. In models with positive externalities or agglomeration economies, there may be multiple equilibria or steady states. If so, then *historical* accidents might get "locked in" through the self-reinforcing logic of virtuous circles (Bleakley and Lin 2012). Alternatively, the key determinant of equilibrium selection might be coordinated *expectations* (Krugman 1991; Matsuyama 1991).

To see this, consider an example of residential location choice. If moving is costly, then households will be interested not only in current neighborhood conditions but also neighborhood conditions in the future. And if households care about the size of a neighborhood because of agglomeration externalities, then future neighborhood conditions depend on the choices of others. Thus, there is the potential of self-fulfilling prophecy: if, for example, everyone thinks that the quality of life in a particular neighborhood will improve, they may act accordingly by moving in. These actions may then improve the attractiveness of the neighborhood, proving expectations correct. And if these endogenous factors are strong enough, then neighborhood improvement might be permanent, even absent changes to fundamentals.

Identifying this expectations channel can be challenging, in part because expectations are hard to measure and in part because expectations may be correlated with neighborhood factors, including the realizations of expected future shocks. In this study, we consider large, long-planned, and salient and well-publicized local investments that were widely expected to affect neighborhood quality of life, thus addressing the challenge of measuring expectations. Further, decades later, many of these planned local investments were cancelled permanently, thus breaking the link between expected versus realized shocks.

Our approach examines historical planned highway segments within U.S. cities that were expected to reduce future neighborhood quality of life. In the mid-1950s, there was widespread consensus that urban highways would be built; highway builders enjoyed broad support and few constraints. It was also widely understood that urban highways would have significant negative local quality of life effects on central neighborhoods through noise, pollution, and barrier effects (Brinkman and Lin 2022). The grassroots protests known as the freeway revolts are *prima facie* evidence of these expected disamenities. While the freeway revolts had little initial success in altering or blocking urban highway construction, federal and state reforms eventually led to the permanent cancellation of some highway projects and their dependent segments, especially after 1973. These cancellations meant that expected future neighborhood disamenities from *completed* highways never materialized. In many cases, which highway segments were planned and which were cancelled depended on idiosyncratic factors that were unrelated to neighborhood confounders. Therefore, this setting addresses both the challenges of measuring expectations and identifying their effects.

We provide evidence that planned highways in the mid-1950s caused neighborhood decline, and that these declines persisted even after planned highways were cancelled in the mid-1970s. We use spatial data on completed highways and highway plans from the 1955 "Yellow Book," the first national publication describing the planned routes of highways *within* cities (U.S. Department of Commerce 1955). We combine these with neighborhood population, demographics, and fixed characteristics 1940–2010 from a new consistent-boundary census tract panel extending Lee and Lin (2017).

Central neighborhoods near completed highways experienced population declines of 16% between 1950 and 1970, and this decline persisted through 2010, consistent with Brinkman and Lin (2022). Surprisingly, neighborhoods near planned, *but never constructed*, highways experienced declines of 10% between 1950 and 1970, despite having avoided the direct negative effects of new highways. These declines also persisted through 2010. Since the planned highway was never built, these results suggest that self-fulfilling expectations played a decisive role in neighborhood development.

We address several potential confounding factors in our analysis. Highway were unlikely to have been randomly allocated to neighborhoods. There are two relevant selection margins of concern. One, planned highways may have been routed through neighborhoods expected to decline. Two, planned highways may have been more likely to have been cancelled in neighborhoods expected to decline. Either could provide an alternative explanation for our results. However, there is little support for either explanation in historical narrative evidence. Planned highways targeted neighborhoods that were then-underdeveloped (conditioned on observables) and thus had higher growth potential, which would cause us to underestimate the negative effects of planned and built highways. Highway construction was cancelled in some neighborhoods not because of they were themselves controversial, but because of connections to other distant segments.

We use several different designs to estimate the effects of planned highways. First, we use regression adjustment to control for city–year effects and time-varying effects of natural and historical neighborhood factors such as rivers, slope, proximity to the city center, and 1940 and 1950 demographics. Second, we use an inverse probability weighted regression adjustment (IPWRA) estimator that combines matching and regression. Third, we use an instrumental variables (IV) estimator. We follow the literature and use planned and historical intercity route instruments (Baum-Snow 2007; Duranton and Turner 2012; Redding and Turner 2015). We also develop a new *distant delayed completion* instrument to address potential endogenous freeway cancellation. This instrument relies on within-city variation from the pre-1956 completion of connecting, but distant, rural segments of the Interstate highway program. Fourth, we use a matched runner-up estimator that compares outcomes for blocks along the proposed Crosstown Expressway in Philadelphia with an early alternative route considered by planners in the 1910s. Taken together, our results suggest that negative selection of neighborhoods into the highway plan or cancellation treatments is not a concern. Planned highway segments appear to have caused neighborhood decline in advance of construction, and these declines persist to this day, decades after cancellation.

We develop a dynamic model of household neighborhood choice to rationalize these results and quantify local economies of density. The two key features are forward-looking behavior and economies of density in residential location choice. Together, these features can lead to multiple steady-state spatial configurations, and they can rationalize both self-fulfilling expectations (expected future decline in neighborhood quality of life leads to neighborhood decline today) and path dependence (neighborhood decline persists, even when the future shock is never realized.)

In the model, neighborhood quality of life depends on both exogenous factors and an endogenous agglomeration factor that increases with neighborhood population. Households face migration frictions and are forward-looking. There is a steady-state equilibrium path where the larger neighborhood features superior quality of life. However, multiple steady-state equilibria are possible if agglomeration economies are strong relative to the exogenous amenity differences across neighborhoods. Intuitively, strong agglomeration benefits can compensate for inferior exogenous amenities.

We use the model and data to make inference about the strength of agglomeration economies. Initially, the economy is in a steady state where the neighborhood with superior *exogenous* amenities is larger. A shock is announced that will reduce future neighborhood quality of life in this neighborhood only. If the size of the announced negative shock is large enough relative to the agglomeration externality, the neighborhood will begin to shrink, before the shock is realized, as it transitions to a new steady-state equilibrium size. Later, the announced negative shock is cancelled. If the transition has advanced far enough, and the externality is strong enough, then the economy will continue to transition to the new steady-state equilibrium outcome. We characterize these conditions where temporary shocks to expectations can lead to permanent or persistent neighborhood change.

In the dynamic spatial model of Allen and Donaldson (2020), the sizes of regions depend on natural, historical, and contemporaneous factors. Strong *historical* spillovers from fixed legacy investments admit the possibility of multiple steady states and persistent effects of temporary historical shocks, or history dependence. They characterize conditions under which, conditioned on nature and history, the future path of the spatial economy is uniquely determined. In contrast, our results suggest that urban spatial structure is not fully determined, even conditioned on natural and historical factors (Lin and Rauch 2022). Instead, in the context of forward-looking households and strong contemporaneous agglomeration externalities, expectations may play a decisive role.

Our paper also improves our understanding of externalities and coordination in neighborhood development. In Owens III, Rossi-Hansberg, and Sarte (2020), residential externalities and the absence of coordination among developers and residents explains vacant land in central Detroit, even with sound fundamentals. In comparison, our theory incorporates dynamics to highlight an explicit role for expectations and we provide evidence for this channel. In Hornbeck and Keniston (2017), widespread simultaneous reconstruction following the Boston Fire appears to have generated substantial economic gains, perhaps by better coordination of building investments that generate positive externalities. In comparison, our setting more clearly highlights the role of expectations in determining urban spatial structure.

2 Data

We compile and construct data from several sources for our analysis. Data on highway plans come from the "Yellow Book" plans from 1955 (U.S. Department of Commerce 1955) digitized by Brinkman and Lin (2022). These were the first published plans with national scope describing the planned routing of highways within cities. Data on highway construction comes from ESRI (2010), a database of line features for all limited-access highways in the U.S in 2010. These data describe built highway segments. (We hand-corrected these data to account for a small number of highway segments that were built but demolished in the 1980s and later, such as the Embarcadero Freeway in San Francisco.)

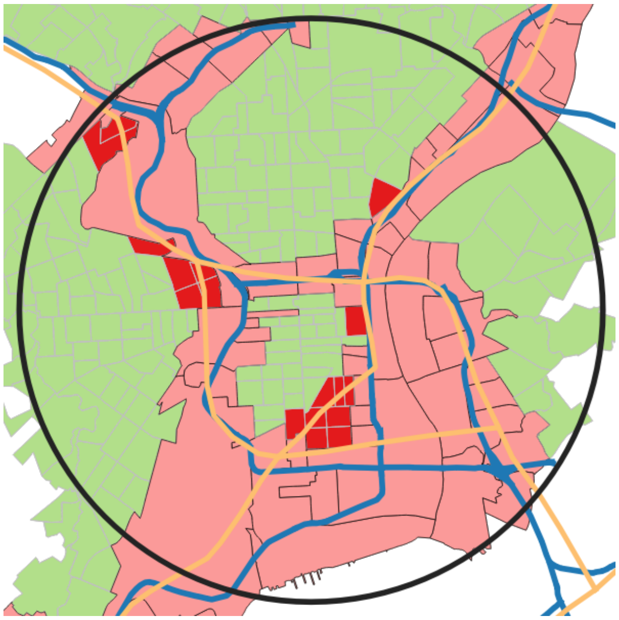
The Yellow Book plans were developed by state highway departments and coordinated by the Bureau of Public Roads (BPR), the federal agency that preceded the Federal Highway Administration. Thus, the Yellow Book plans represent one version—from 1955—of the many iterations of highways plans over the decades. The earliest attempts to develop a national highway network began in the 1910s, with a patchwork of federal, state and local planning. Following the 1956 highway act that authorized and financed the Interstate system, state highway departments were given wide latitude in implementing the plans. Despite the many highway plan iterations, the Yellow Book closely predicts the routing of current built highway segments. Figure 1 shows the Yellow Book plan and built highways in four U.S. cities. There is a high spatial correlation between the Yellow Book plan and highways that were actually built. Across 50 U.S. metropolitan areas, Brinkman and Lin (2022) find a high tract-level correlation between Yellow Book plans and built highways, exceeding 0.8.

One implication of the existence of a patchwork of highway plans over the decades is that we may under-estimate the negative effects of built highway and planned highway segments. Other plans may have shown different routings. Thus, in using the Yellow Book plans, there is likely some misclassification of neighborhoods—some Yellow Book neighborhoods were likely to never have been seriously considered for highways, while non-Yellow Book neighborhoods may have been more certain to have been slated for highways. Because of this misclassification, our analysis likely understates the effect of planned highway segments on neighborhoods.

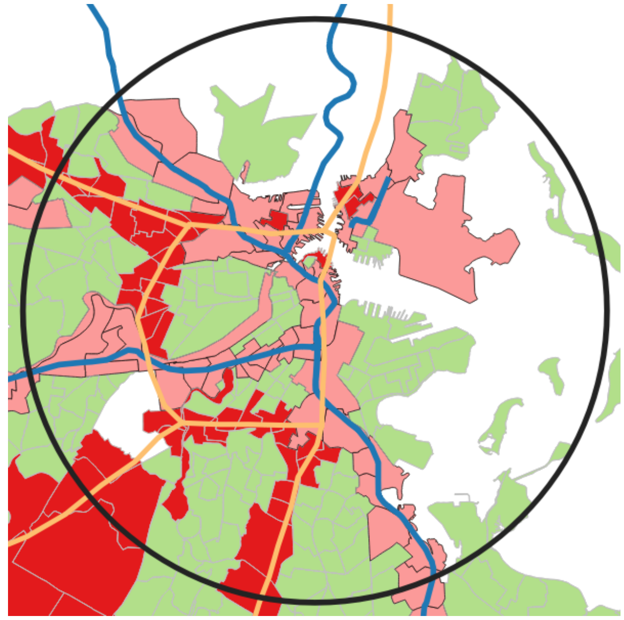
We use a consistent-boundary census tract panel between 1940 and 2010. This is an updated version of the database developed by Lee and Lin (2017). Since tract boundaries change over time, these data are normalized to 2010 boundaries using area weights, or, in later years, block population weights. Census tables provide information about population and housing in each tract and census year.

We compute each tract's distance to the city's center, a point in space defined using the 1982 Census of Retail Trade (Fee and Hartley 2013). Holian (2019) compares alternative measures of city centers and concludes that the 1982 Census of Retail Trade is "probably the best measure of the [central business district] concept."

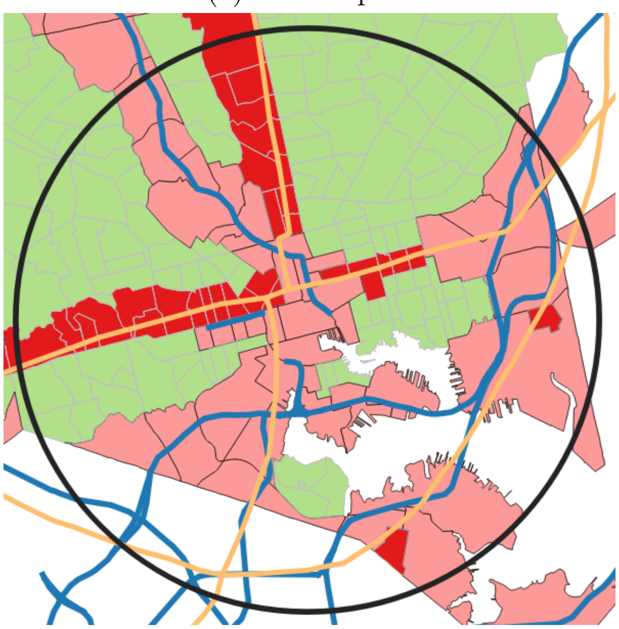
We limit our analysis to tracts within 5 miles of city centers. This is because we want to focus on neighborhoods where highways had net negative local effects. In the model of



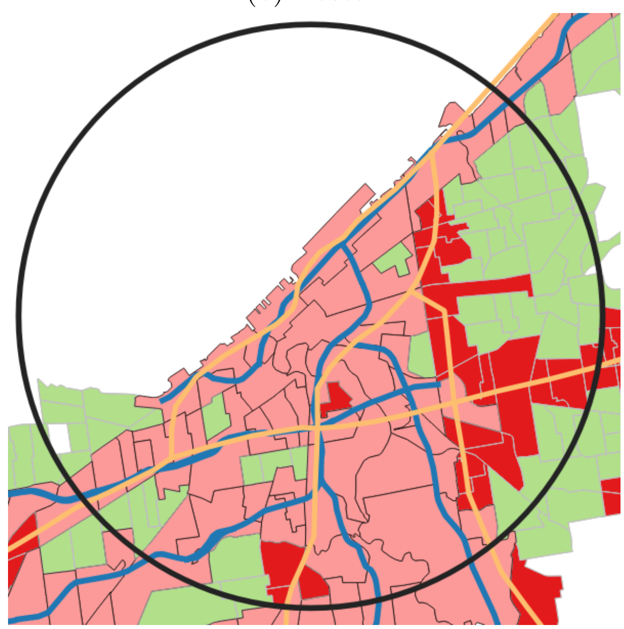
(a) Philadelphia



(b) Boston



(c) Baltimore



(d) Cleveland

Figure 1: Yellow Book plans and built highways in four cities

This figure shows Yellow Book plan routes (yellow lines), built highways (blue lines) and areas within 5 miles of city centers (black circles). Background geographic units are 2010 Census tracts with valid 1940 data. Tracts are classified into one of three mutually exclusive and exhaustive groups: (i) Plan Not Built (red), (ii) Built (pink), and (iii) Not Built (green).

Brinkman and Lin (2022), highways reduce local quality of life. This is effect is localized in the sense that disamenities reduce quality of life in neighborhoods close to highways more compared with neighborhoods far from highways. However, the benefits of highways—from access to regional destinations like employment centers—vary with centrality. These benefits are modest in the center of the city, which already had superior *ex ante* access, but larger in the suburbs, which benefit significantly from faster travel speeds. Thus, the net local effect of highways is more negative near downtown.

These choices yield a balanced panel database with more than 4,000 census tracts in 41 metropolitan areas that (i) are within 5 miles of city centers, (ii) have available Yellow Book plans, and (iii) have available 1940 tract data. We also explore robustness to alternative sample selection below.

Next, we define treatment and comparison groups. Each tract is allocated to one of three mutually exclusive and exhaustive groups. One, "built" tracts (B) contain a built highway. Two, "planned, not built" (PNB) tracts contain a 1955 Yellow Book planned route and do not contain a built highway. Three, "not planned" (NP) tracts do not contain a built highway nor a 1955 Yellow Book planned route. Later, we also explore robustness to an alternative *spatial* definition, where treatment intensity varies with (log) distance to the nearest planned or built highway segment.

Figure 1 illustrates these classifications for four U.S. cities. B tracts are pink, PNB tracts are red, and NP tracts are green. Note again that because we are interested in the effects of planned highways through anticipated declines in quality of life, we focus only on tracts within 5 miles of the city center, circumscribed by black circles.

In our sample of 41 cities, 53% of tracts are in the NP comparison group. 10% of tracts are in the PNB treatment group. 37% of tracts are in the B treatment group.

3 Evidence

We estimate the effect of planned, but not built (PNB) highway segments on neighborhoods. We also estimate the effects of built (B) highway segments. B neighborhoods declined in size compared with neighborhoods never planned (NP) for highways. Surprisingly, PNB neighborhoods also suffered declines, despite having avoided the direct negative effects of new highways.

3.1 Simple contrast

The first estimator assumes that the allocation of planned and built highways to neighborhoods was at random. If highway plan assignment is mean independent, then a simple contrast between the PNB and NP groups identifies the causal effect of planned but never constructed highway segments. Similarly, a simple contrast between the B and NP groups identifies the causal effect of built highway segments.

Figure 2 shows sample means of log neighborhood household population by census year for the three groups. Vertical lines show 1956, the year of the passage of the Federal-Aid Highway Act, and 1973, the year of the passage of a revised Federal-Aid Highway Act that first allowed for the permanent cancellation of some planned Interstate segments.

A few qualitative features stand out. First, population increased for all three groups between 1940 and 1960.

Second, in the 1940–1950 decade before the Interstate highway act, B and PNB neighborhoods grew at similar or slightly faster rates compared with NP neighborhoods. Thus, pre-trends suggest that NP neighborhoods may provide appropriate counterfactual outcomes (or even slightly negatively selected outcomes) for B and PNB neighborhoods.

Third, in 1950, B and PNB neighborhoods were slightly larger on average compared with NP neighborhoods. This is due to the tendency for B and PNB neighborhoods to be closer to the city center compared with NP neighborhoods; we control for this factor later. Still,

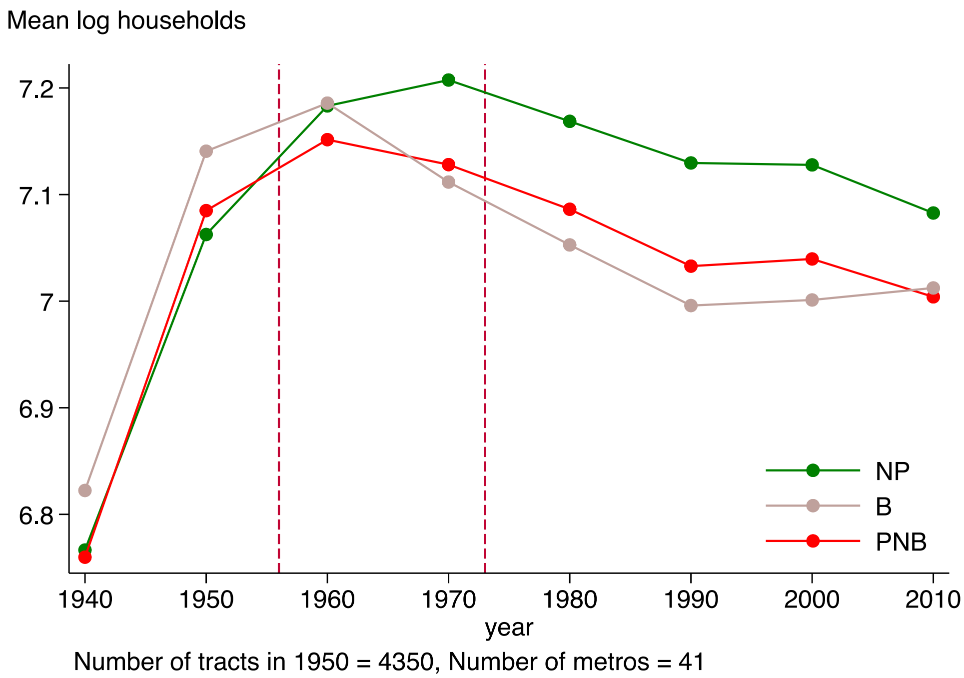


Figure 2: Average household population by year by treatment or comparison group

This figure shows mean log household population by census year for three groups of tracts. NP is not planned; PNB is planned, not built; and B is built. Vertical lines show 1956, the year of the passage of the Federal-Aid Highway Act, and 1973, the year of the passage of a revised Federal-Aid Highway Act that first allowed for the permanent cancellation of some planned Interstate segments.

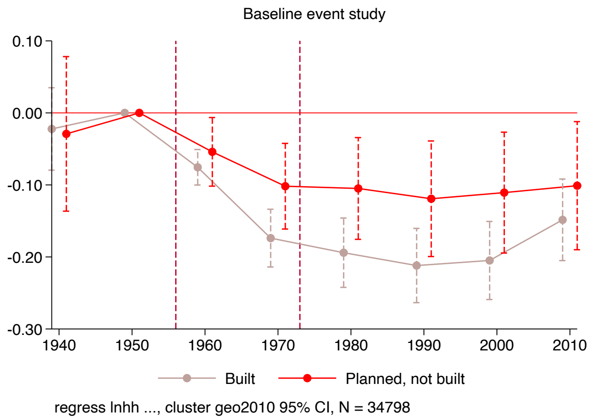
the initial size advantage of B and PNB neighborhoods sets up a reversal-of-fortune result.

Fourth, between 1950 and 1960, household population growth slows markedly, especially in B and PNB tracts. Between 1960 and 1970, household population declines in B and PNB tracts; in contrast, household population continued to increase in NP tracts. These two decades (1950–1970) correspond to the period of most active highway planning and construction. (Almost three-quarters of planned Interstate mileage was completed by 1970.) Notably, by 1970, the reversal of fortune is complete.

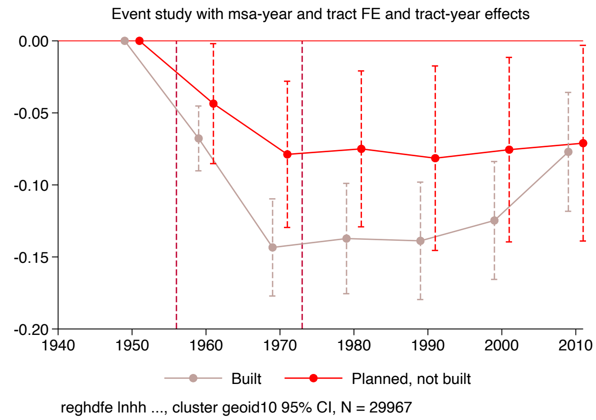
At first, the freeway revolts had little success in blocking or changing planned freeway segments. But policy began to respond to the concerns of neighborhood groups in the middle to late 1960s. For example, highway legislation in 1966 and 1968 created new environmental and historic-preservation hurdles for new highway construction. By 1967, "the freeway debates and protests[...] began 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). A key new measure in the 1973 highway act allowed state and local governments to cancel planned Interstate segments, and even substitute funds for mass transit projects. Moreover, some planned segments were cancelled not because they were themselves controversial, but because they connected to other distant segments that were controversial. A special report from the Federal Highway Administration (1970) details many of these so-called "dependent segments."

Figure 2 also shows that, after 1970, there is little evidence of relative recovery of neighborhoods near PNB and B highways compared with NP neighborhoods. The declines of neighborhoods near planned but never constructed highways and neighborhoods near built highways appear persistent. In the case of PNB neighborhoods, these declines persisted despite the cancellation of the planned highways.

We can more formally estimate these differences in regression. For each census year t, we regress the log change in household population of tract g since 1950 $\Delta \log N_g$ on the binary highway treatments B and PNB. This yields estimates of the mean differences across groups



(a) Event study



(b) With regression adjustment

Figure 3: Simple contrast and regression adjustment estimates

Panel A: Coefficient estimates from an event study regression of tract log population on full set of highway treatment indicators and census year interactions. Whiskers show 95% confidence intervals based on standard errors clustered on census tract. Panel B: Coefficient estimates from a specification including metro–year fixed effects, tract fixed effects, and time-varying effects of natural and pre-determined tract characteristics.

by year, β_t and ϕ_t, corresponding to the gaps shown in Figure 2.

$$\Delta \log N_{g(t)} = \alpha + \beta_t 1(B)_g + \phi_t 1(PNB)_g + \varepsilon_g \tag{1}$$

Figure 3a shows the results. 1950 is the base year. NP neighborhoods are the base (omitted) category, so the estimates of β_s and ϕ_s compare B and PNB neighborhoods, respectively, versus NP neighborhoods in each year. Whiskers show 95% confidence intervals based on robust standard errors.

We find that by 1970, PNB tracts declined 9.7% compared with NP tracts. In addition, these declines persisted through 2010, more than 30 years after the cancellation of many of these highway projects. These effects are smaller than the effects of completed highways. B tracts declined 16% compared with NP tracts by 1970, and these declines also persisted through 2010.

3.2 Causal inference: Narrative evidence on selection

We address factors that could confound causal inference. Highway were unlikely to have been randomly allocated to neighborhoods. There are two relevant selection margins of concern. One, planned highways may have been routed through neighborhoods expected to decline. Two, planned highways may have been more likely to have been cancelled in neighborhoods expected to decline. Either could provide an alternative explanation for the decline of neighborhoods near planned or built highway segments.

However, there is little support for either explanation in historical narrative evidence. Both planned and constructed highways targeted neighborhoods that were then-underdeveloped (conditioned on observables) and thus had higher growth potential, which would cause us to underestimate the negative effects of planned and built highways. In a statement submitted to Congress in 1955, Commissioner of Public Roads C.D. Curtiss cited several criteria the BPR considered in designating urban Interstate routes; most relevantly, the BPR recommended routes on undeveloped land and routes that followed forecasted demand growth (Weingroff n.d.). Both criteria suggest positive selection of planned Interstate routes on neighborhood growth factors. These patterns were codified by the American Association of State Highway and Transportation Officials (AASHTO, 1957) in the "Red Book," which recommended routes on undeveloped land.

With respect to the second margin (endogenous cancellation), Brinkman and Lin (2022) find that neighborhoods that were highly educated and white in 1950 were more likely to succeed in blocking proposed highways in the 1970s. Compared with the positive selection into planned routes on neighborhood growth factors, it is less clear whether or not these patterns suggest positive selection into cancellation. However, the narrative evidence does not clearly suggest that our findings are driven by negative selection into cancellation on neighborhood growth factors.

3.3 Regression adjustment

We use several estimators that rely on weaker assumptions than mean independence on the allocation of planned and built highways to neighborhoods.

First, the simple contrast results are robust to including regression controls. Figure 3b shows the results from a specification that includes metro–year fixed effects, census tract fixed effects, and time-varying effects of natural and historical neighborhood characteristics. Metro–year fixed effects control for metropolitan factors affecting neighborhood growth. In other words, including metro–year fixed effects means that we are comparing tract growth *within* metropolitan areas. Tract fixed effects absorb any time-invariant tract-level growth factors. For example, highways tended to be routed near rivers and coastlines. Tract fixed effects account for constant growth effects of rivers and coastlines. Finally, we control for time-varying effects of natural and historical neighborhood characteristics. We create indicator variables for proximity (within 1 kilometer) to a river, a lake, a shoreline, or a seaport. We also create indicators for quintiles of distance to the city center, minimum January temperature, maximum July temperature, annual precipitation, average slope, the non-white shares in 1940 and 1950, log household population in 1940 and 1950, log housing units in 1940 and 1950, and log land area. In addition to quintiles of distance to the city center, we control for log distance to the city center. All of these tract characteristics are interacted with census year dummies. (As a result of controlling for household population in 1940, the 1940 coefficients can no longer be reliably estimated.)

The results are quantitatively similar to the simple contrast estimates. By 1970, PNB tracts declined 7.6% compared with NP tracts (versus -9.7% from simple contrast), and these declines persisted. B tracts declined 13.6% compared with NP tracts (versus -16.0% from simple contrast), and these declines persisted after 1970.

3.3.1 Robustness and other outcomes

Our results are robust to sample selection. We experiment with alternative classifications of 1940 census tracts, holding constant the goal of identifying neighborhoods with central locations near commuting destinations where the net effect of highways was likely negative. Our results are robust to using samples of (i) the top 25% of tracts in each city by 1940 household popualtion density; (ii) tracts with greater than 14,000 population per square mile in 1940; (iii) tracts with greater than 4,000 housing units per square mile in 1940.

Our results are also robust to defining a spatial treatment versus a binary treatment. We repeat our analysis, substituting log distance to B and PNB highway segments for tract indicators. These spatial treatment definitions address the concern that small re-routings of planned highway segments could account for our results. For example, if a planned segment was re-routed to a parallel route 1 mile away, then the decline of PNB neighborhoods might be attributed to the effects of a somewhat more distant built highway. The specification using a spatial treatment controls for this confounding factor. The results are shown in Figure A.1. The figure shows opposite (positive) signed coefficient estimates, which is expected given that closer proximity to a highway segment is associated with smaller values of the variable. These results show qualitatively similar patterns compared with our main results.

We also consider other outcomes. Results using total population are quantitatively nearly identical.

Figure A.2 shows substantial declines after 1960 in the number of habitable housing units in B and PNB neighborhoods. This suggests substantial disinvestment in the housing stock.

Figure A.3 shows large absolute declines in total white populations in B and PNB neighborhoods and large relative declines in total nonwhite populations in B and PNB neighborhoods. (This is in the context of white flight and Black migration into city centers.) Our interpretation is that both white and black households prefer to avoid the negative local effects of highways. On net, these leaves a modest and insigificant decline in the nonwhite share in B and PNB neighborhoods.

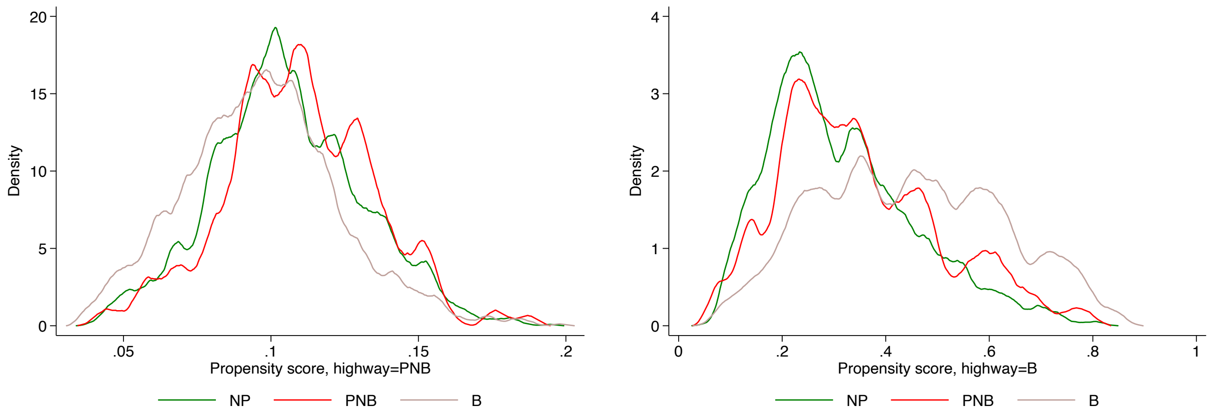
Finally, Figure A.4 shows a modest and insigificant decline in average household income in B and PNB neighborhoods. Households of different incomes may vary in their valuation of housing, their valuation of the freeway disamenities, or their valuation of the access benefits of freeways. As noted by Brinkman and Lin (2022), the presence of multiple sources of household heterogeneity make pure theoretical predictions of sorting responses to highways ambiguous.

3.4 IPWRA estimates

Next, we use the inverse probability weighted regression adjustment (IPWRA) estimator (Wooldridge 2007). This estimator combines matching and regression and accounts for selection by weighting observations in the control group based on similarities to the treatment group. This is a two-step estimator. In the first step, we estimate the probability of treatment conditioned on a set of observed factors W. In the second step, we estimate treatment-level mean outcomes with inverse probability weights (obtained from the first step), conditioned on a set of observed factors X. The estimate of the average treatment effect is the contrast between the predicted treatment-level means obtained from the second step.

This estimator assumes that highway treatment is strongly ignorable conditioned on observed factors affecting highway treatment in W and population in X. The estimator is doubly robust. If either the treatment model or the outcome model are correctly specified, then the IPWRA estimator is a consistent estimator of the average treatment effect. Intuitively, the inverse probability weights obtained in the first step magnify the comparison group units that look like the treated (on covariates in W), and vice versa. The regression adjustment in the second step accounts for differences in observed covariates in X across the treatment and comparison groups. Thus, the IPWRA estimator has two chances to “get it right.”

We use the same vector of tract characteristics for both W and X. We include the same controls for natural and historical factors as in the previous section.



(a) $\widehat{Pr(PNB)}$ (b) $\widehat{Pr(B)}$

Figure 4: Overlap in propensity score distributions

Overall, there is good overlap in estimated propensity scores from the first step. PNB tracts look very similar compared with NP tracts on propensity scores. B tracts look somewhat less similar, but there is good overlap in the propensity score distributions. Figure 4 shows this overlap.

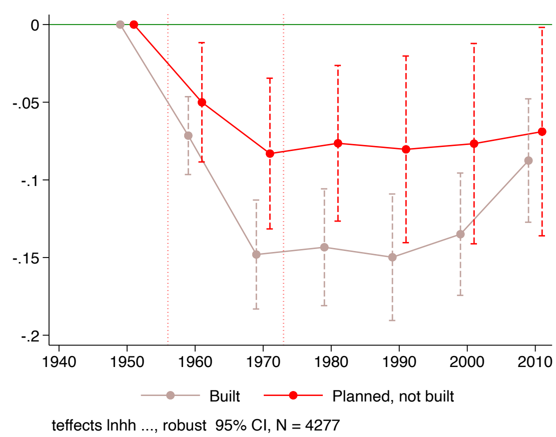


Figure 5: IPWRA estimates

This estimator yields quantitatively similar estimates for the effects of PNB and B. Figure 5 shows these results. By 1970, PNB tracts declined 8.0% compared with NP tracts, and B tracts declined 13.8% compared with NP tracts. These are quantitatively similar to our earlier estimates of -7.6% and -13.6% for PNB and B, respectively, obtained by regression adjustment alone. The persistent declines following cancellation similarly echo the simple contrast and regression adjustment estimates.

3.5 IV estimates

We use instrumental variables (IV) to estimate the effect of planned highway segments. Recall that we have two endogenous margins of selection: selection into the highway plan, and then, conditioned on selection into the highway plan, selection into cancellation. Alternatively, we also have two endogenous treatments: PNB and B. Thus, we need at least 2 instruments.

We start with a set of *inter*city historical and planned routes as instruments. These are good predictors of planned *intra*city highway segments. We follow the literature in the use of these instruments (Redding and Turner 2015). Following Baum-Snow (2007), we use the 1947 intercity highway plan. The goal of the 1947 plan 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 planned-highway instrument is determined by the number and orientation of nearby large metropolitan areas. For example, the north-south orientation of I-35 through Austin, Texas, is determined by the orientation of Austin compared with Dallas (north) and San Antonio (south), rather than neighborhood factors.

We also construct a variant of this instrument that instead connects via shortest-distance routes all city center pairs connected by the 1947 plan without going through 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; the variant instrument shifts this route westward and northward.

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 (U.S. Geological Survey 1970), and historical railroads in operation by 1898 by Atack (2015). These planned and historical routes were re-digitized by Brinkman and Lin (2022), as the original constructed instruments in Baum-Snow (2007) and Duranton and Turner (2012) contain only cross-metropolitan variation, with insufficient spatial detail for neighborhood-level analysis.

We also develop a new *delayed distant completion* instrument to address potential endogenous freeway cancellation. This instrument is new to the literature. The basic idea relies on two features of the Interstate highway program.

One, some rural sections of the national highway network, far away from city centers, were completed before 1956 under earlier state and federal highway programs. In this era and earlier, which (rural) highway segments were completed first often depended on idiosyncratic factors (Johnson 1965). Further, the early completion of rural highway segments likely had little to do with central neighborhood factors. Despite their eventual extent, the freeway revolts were largely unanticipated by planners, builders, and even later critics of the Interstate program—the early rural segments faced no local opposition.

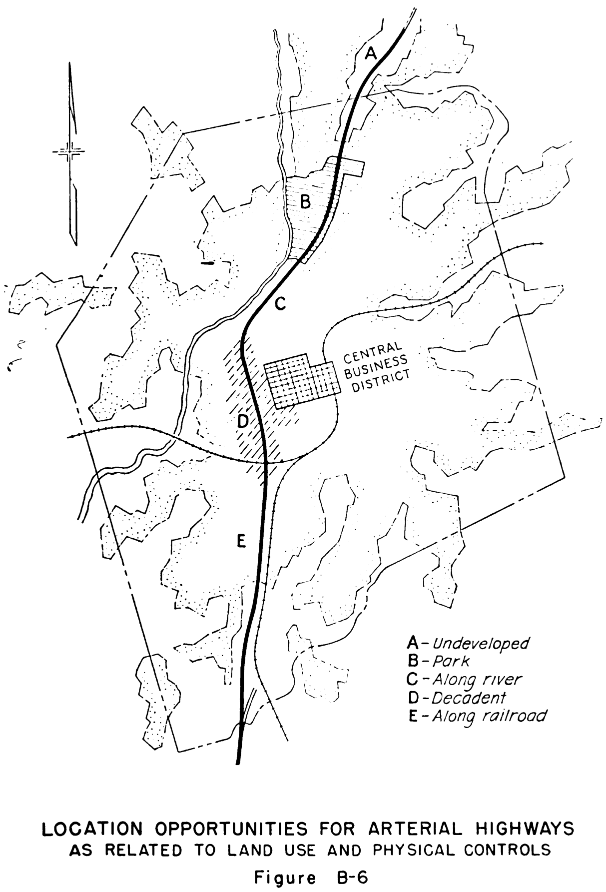
Two, uniform design standards under the Interstate program called for highway rays that converged to the central business district. Consider the schematic diagram of a hypothetical city from the AASHTO's "Red Book" (1957) in Figure 6a. Early design standards called for highway construction along "rays" that converged near the central business district. Here, two segments labeled (i) A–B–C and (ii) D–E represent two distinct rays approach the city center from the north and south, respectively.

Our delayed distant completion instrument relies on the idea that early completion (or not) of rural routes *beyond* segments A or E affect the later completion of intracity highway segments. To fix ideas, suppose that a rural segment to the north, just beyond A, was completed before 1956, but a rural segment to the south, just beyond E, was not. Because of the design standards that specified highways ray emanating out from the central business district, the early completion of rural rays beyond segment A increased the likelihood that planned uban segments A–B–C to the north of the city center would be completed to plan. Conversely, the delayed or lack of completion or rural rays beyond segment E decreased the likelihood that planned urban segments D–E would be completed to plan.

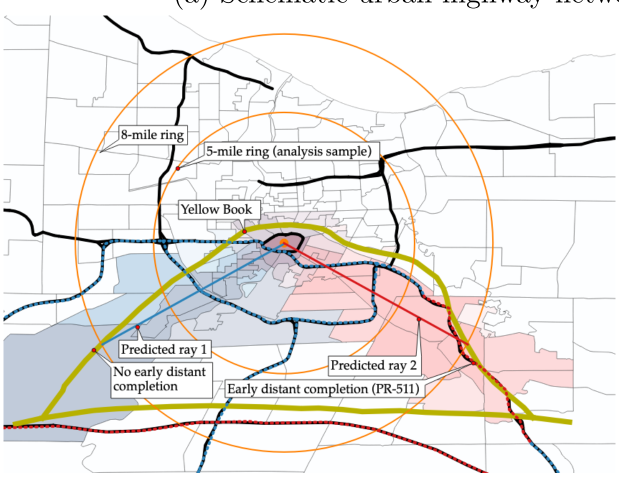
Figures 6b and 6c illustrate the construction of our early distant completion and delayed distant completion instruments for two cities, Rochester and Houston. In Figure 6b, the Yellow Book describes two planned rays emanating from downtown Rochester to the southwest and southeast. It also shows a peripheral route on the outskirts of the city, which we ignore.

We do not want to use the actual Yellow Book routes in central cities to construct our instrument, since the routing of the Yellow Book plan routes was likely endogenous for the reasons outlined earlier. Instead, we construct *predicted* routes based on the general orientation of the rays with respect to the city center. In practice, we use the intersection of the planned Yellow Book routes and a circle with 8-mile radius around the city center. Recall that our sample only includes tracts within 5 miles of city centers. For the construction of this instrument, we only use spatial information beyond 8 miles of city centers. Thus, the predicted rays have the same general routing of the actual planned rays, but deviate from the actual planned routing because they rely only on relative position of regional or intercity destinations. In this way, this instrument is a somewhat more local version of the intercity 1947 plan instrument by Baum-Snow (2007).

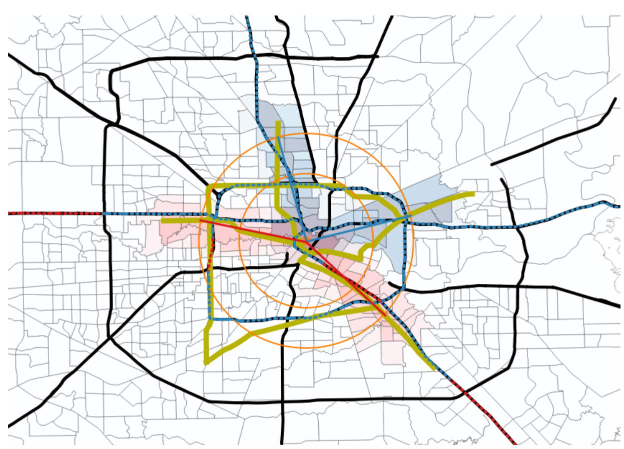
Predicted rays in hand, we then turn to classifying rays according to early (or not) distant completion. We rely on the PR-511 database compiled by the Federal Highway Administration, which includes information on date first open to traffic by Interstate highway segment. In the case of Rochester, there is a segment beyond predicted ray 2 that was completed before 1956 (as indicated by the red dotted lines). In contrast, the segment



(a) Schematic urban highway network design from the 1957 Red Book



(b) Rochester



(c) Houston

Figure 6: Constructing early and delayed distant completion instruments

beyond predicted ray 1 was not completed before 1956. As a result, we classify predicted ray 1 as a "delayed distant completion" and predicted ray 2 as an "early distant completion."

After classifying predicted rays, we then measure each tract's distance separately to the nearest early distant completion predicted ray and to the nearest delayed distant completion predicted ray. The shading of each tract in Figure 6 reflects these two calculations: tracts in shades of blue are closer to a delayed distant completion predicted ray, while tracts in shades of red are closer to an early distant completion predicted ray.

Figure 6c shows the construction of our instruments for Houston. We defined 4 predicted rays based on intersections with Yellow Book plan rays and the 8-mile circle. Two predicted rays connected to distant segments that were completed before 1956. These early completions were on I-10 (heading west to San Antonio) and along I-45 (heading southeast to Galveston). In contrast, two other predicted rays did not connect to segments that were completed before 1956. These are classified as delayed distant completions.

We use the two-step IV estimator of Wooldridge (2010) (Procedure 21.1) for estimating the effects of binary endogenous treatment. This is a two-step estimator. In the first step, we estimate a multinomial logit model of $Pr(w = j|\mathbf{X}, \mathbf{Z})$ by maximum likelihood, where j can take the values B, PNB, or NP. Then, we obtain the fitted probabilities, $\hat{G}_g$. In the second step, we estimate the following equation by 2SLS using instruments 1, $\hat{G}_g$, and $\mathbf{X_g}$. We separately estimate this equation by census year, to obtain IV estimates of the effect of B and PNB in each census year. The control variables in $\mathbf{X}$ are the same natural and historical factors used previously. The instruments $\mathbf{Z}$ include separate indicators for tracts containing intercity plan, historical, early or delayed distant completion routes, as well as log distance to the nearest IV route.

$$\Delta \log N_{g[m]} = \alpha_0 + \alpha_m + \mathbf{X_g}\gamma + \beta 1(B)_g + \phi 1(PNB)_g + \varepsilon_g \tag{2}$$

This estimator has several nice features. One, the usual 2SLS inference is asymptotically valid (Wooldridge 2010). Two, it is the optimal feasible instrument if step 1 is correctly spec-

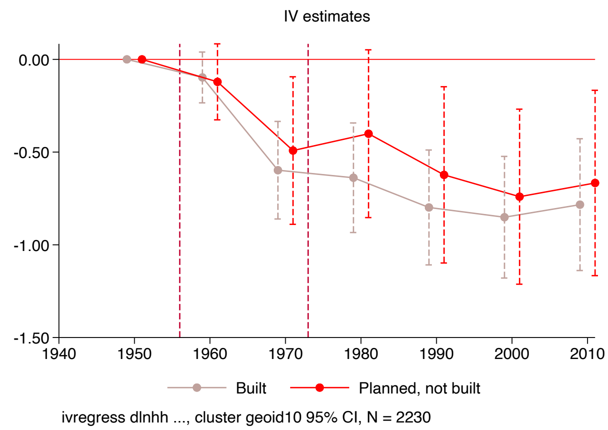


Figure 7: IV estimates

ified; it is a consistent estimator even if step 1 is incorrectly specified. Three, the nonlinear form improves efficiency and addresses potential weak instrument problems (Xu 2021). In practice, a linear 2SLS estimator delivers similar point estimates but larger standard errors.

Figure 7 shows IV estimates of the effect of planned but never built segments and built segments. Qualitatively, the estimated effects and their dynamics line up with previous results. Both PNB and B neighborhoods decline by 1970, and these declines persist until 2010, despite the cancellation of highway segments. Quantitatively, the effects are larger. By 1970, PNB tracts declined 39% versus NP tracts. B tracts declined 45% versus NP tracts. Thus, we obtain qualitatively similar results compared with the simple contrast estimates, but they are three to four times as large.

There may be several rationalizations for why the IV estimates are inflated versus the simple contrast: misclassification of treatment, positive selection into plan or cancellation, and/or the IV is identifying a local average treatment effect.

One potential explanation for the inflation of the IV estimates is that the Yellow Book plans have misclassified some neighborhoods. Over the decades of highway planning and construction, there were many iterations of highway plans. This would lead simple contrast to underestimate the effects of planned and built highways.

A second potential explanation is that there was positive selection into plan and cancellation on growth factors. This is consistent with the narrative evidence presented earlier than highway plans were allocated to neighborhoods expected to grow the most. Thus, the simple contrast may underestimate the causal effects of planned and built highways.

Finally, the IV estimator may be identifying a local average treatment effect. Intuitively, complier highway segments were more likely to plow through dense, already developed neighborhoods. These neighborhoods likely would have been more negatively affected by highway construction.

3.6 Extensions

3.6.1 Early cancellation has temporary effects

We find that early cancellation has temporary effects on PNB neighborhoods.

There is limited systematic information on the timeline of planning various highway segments. However, we do know that two cities, San Francisco and Baltimore, were exceptional in that they had (and used) local control powers to stop highway construction.

In San Francisco, the Board of Supervisors had the sole power to close roads, effectively giving a local veto over state highway construction within the city limits. The Board of Supervisors cancelled all further highway construction in 1959.

In Baltimore, there were two unique provisions in the city's home-rule charter. The city alone had the sole authority to condemn properties. In practice, this also meant the city had veto power over state highway plans that required the demolition of existing buildings.

We repeat our event-study analysis, focusing only on San Francisco and Baltimore. The results are reported in Figure 8. From 1950 to 1970, both PNB and B neighborhoods reflect similar dynamics compared with the 41-city sample. However, after 1970, PNB neighborhoods revert back to their pre-1950 size.

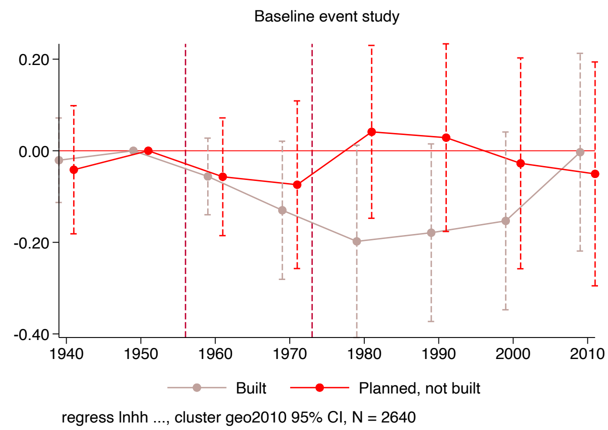


Figure 8: Early cancellation has temporary effects

3.6.2 Matched runner-up estimates

We compare outcomes for blocks along the proposed Crosstown Expressway in Philadelphia with an alternative route considered by planners. The case study of the Crosstown Expressway differs from the earlier analysis in three important ways: (i) it uses a distinct matched runner-up design, (ii) it uses block versus tract-level variation, and (iii) it allows us to control for confounders (such as urban renewal and other public interventions) that are observed in Philadelphia but not consistently measured across our larger panel of U.S. cities.

The proposed Crosstown Expressway was part of the earliest plans for a highway loop around Center City Philadelphia, dating to at least 1911 (T. A. Reiner, Sugarman, and J. S. Reiner 1970). The other three sides of the loop were eventually completed: the Schuylkill Expressway (I-76) on the western side, the Delaware Expressway (I-95) on the eastern side, and the Vine Street Expressway (I-676) on the northern edge of Center City. For the southern segment, early plans showed alternative alignments along either South Street or Washington Avenue. In 1947, the City Planning Commission proposed an alignment along South Street. This route was repeatedly approved and publicized between 1947 and 1964. The first opposition emerged around 1964, centered on the neighborhood of Queen Village. Eventually, the Crosstown Expressway was cancelled and deleted from long-run planning documents at

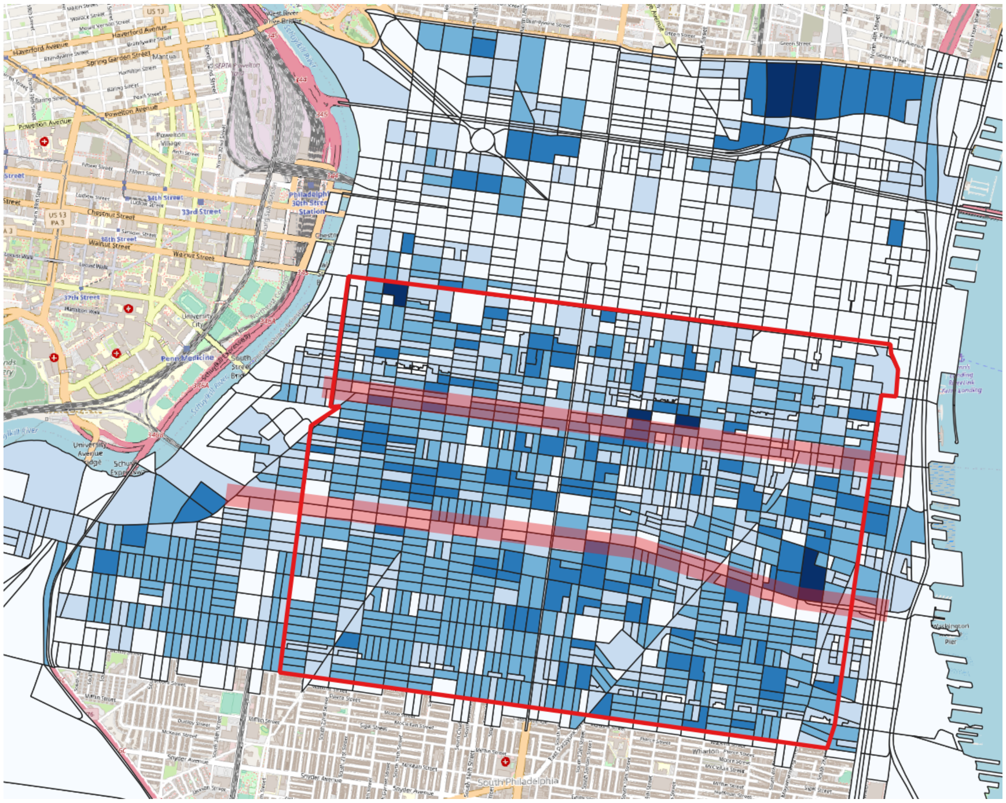
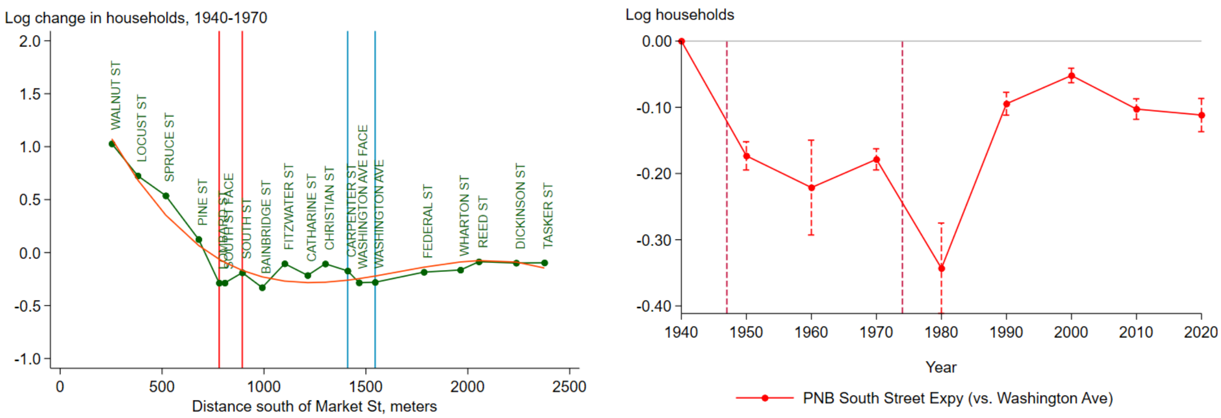


Figure 9: Matched runner up design sample area

the city and state levels between 1974 and 1977.

Our analysis compares South Street, the “winning” planned route, to Washington Avenue, the runner-up planned route. Figure 9 shows blocks in central and south Philadelphia. Our sample area, outlined in red, is bounded by Walnut Street on the north, 2nd Street on the east, Tasker Street on the south, and 24th Street on the west. We exclude blocks north of Walnut Street, which contains the central business district and was and is dominated by non-residential uses. Similarly, we exclude blocks east of 2nd Street due to the location of I-95 and the Delaware River waterfront.

The geographic units are consistent-boundary Census blocks. Blocks are shaded according to 1940 block household population: darker blues have greater 1940 populations. The two proposed alignments are shown as red bands: South Street is the northern band and Washington Avenue is the southern band, about 660 meters to the south. We digitized the



(a) Change in household population, 1940–1970

(b) Matched runner-up estimates

Figure 10: Matched runner-up estimates

block-level data from 1940–1970 for this analysis. We normalized the block data to consistent boundaries using areal weights.

For each census year, we compute the log change in household population from 1940, the only pre-treatment year that we observe. (The first plans advertising the South Street route were published in the late 1940s.)

Figure 10a summarizes 1940–1970 household population growth by block group. Block groups are defined as east-west corridors bounded by major cross streets; for example, the Walnut Street block includes all blocks bounded by Walnut Street on the north and Locust Street on the south. Red vertical lines denote the blocks that might have been affected by the proposed South Street route; Blue vertical lines denote the blocks that might have been affected by a Washington Avenue alignment. Our estimator compares blocks between the red lines versus blocks between the blue lines.

There are two identification issues. The first is that there is a strong spatial trend, evident from Figure 10a. Northern blocks experienced large growth in residential populations after 1940. The increasing residential demand for central locations complicates a direct comparison of South Street versus Washington Avenue, since South Street is proximate to the most central locations.

A second concern is that there may be spatial effects of the proposed highway, at unknown spatial scales. For example, the effect of the planned South Street Expressway may have extended to Pine Street and Bainbridge Street, one block north and south of the South Street corridor. It is possible that these spatial effects may have extended even farther.

We take a conservative approach to address both of these concerns. We fit a spatial trend using a third-degree polynomial to household population growth in each year. This is shown in the orange line in Figure 10a. The matched runner up estimate is then the difference between the orange fitted spatial trend and the green observed outcomes.

This approach is conservative. We are using relatively local variation to project the counterfactual outcomes for the South Street and Washington Avenue corridors. The South Street counterfactual outcome is heavily influenced by the outcomes for the surrounding blocks of Pine Street and Bainbridge Street. Further, any spatial effects spilling over to nearby blocks are effectively absorbed by the spatial trend. To see this, consider an alternative approach fitting a linear trend through the endpoints of Walnut Street and Tasker Street. This would yield larger estimates of the effect of the South Street plan.

The matched runner up estimates are shown in Figure 10b. We find that in 1970 the effect of PNB is -16.4%. These declines persisted after the highway was cancelled in 1974-1977; in 2020, South Street PNB blocks are still 10.6% smaller compared with Washington Avenue blocks. These are likely lower bounds given the identification issues discussed above.

4 Model

First, we lay out the household's choice problem, which follows standard practice in the dynamic discrete choice literature. Next, we define how an equilibrium is obtained for a neighborhood in our model and explore its properties for different utility functions. Lastly, we show how the model can be augmented to allow for empirical implementation.

4.1 Household Choice Problem

A neighborhood j offers a flow of utility benefits from location amenities a and from the population in the neighborhood, n.

$$u(a_j, n_j) = a_j + u(n_j) \tag{3}$$

The household values the stream of utility flows from continuing on in the neighborhood.[1] Our exposition of the model will follow these two examples of the possible shape of the utility function, beginning with Figure 11 in which equilibrium in the neighborhood (to be discussed below) is shown for two example utility functions drawn superimposed on the figures. On the left, there is monotone congestion in population. On the right, utility exhibits congestion for a region of population, then agglomeration, and then congestion again.

In addition to the common component of flow utility, each period the household has the opportunity to choose to remain in the neighborhood or move out to an outside option. Let V denote the value function for behaving optimally, which depends on state variables that affect the utility flow. The choice-specific values for a household originating in the neighborhood are

$$v_j(a_j, n_{j,t-1}) = u(a_j, n_{j,t}) + \beta V(a_j, n_{j,t}) \tag{4a}$$

$$v_0 = u_0 + c_0 + \beta V_0 \tag{4b}$$

where β is the household's discount rate. Moving to the outside option incurs a moving cost c_0. Without loss of generality, we normalize the value of the outside option to be $V_0 = 0$, so that the value of the focal neighborhood is relative to all options outside of it.

[1] The only restriction we place on the value function is that it is bounded so that the value function exists. That is, for some finite values U^- and U^+, $-\infty < U^- < u(a, n) < U^+ < \infty \; \forall a, n$.

When faced with the choice of moving or staying, households receive an idiosyncratic, iid shock to the relative utility of the neighborhood. The optimization problem for the household is then

$$V(a_j, n_{j,t-1}) = max[v_j + \varepsilon, v_0] \tag{5}$$

Making the usual assumption that these shocks are extreme value (Type 1), we have the following properties for the choice probability and continuation value

$$\sigma_{jj}(a_j, n_{j,t-1}) = \frac{exp(v_j)}{exp(v_j) + exp(v_0)} \tag{6a}$$

$$\sigma_{j0}(a_j, n_{j,t-1}) = \frac{exp(v_0)}{exp(v_j) + exp(v_0)} \tag{6b}$$

$$V(a_j, n_{j,t-1}) = \ln[exp(v_j) + exp(v_0)] \tag{7}$$

Similarly, there is a population outside the neighborhood that faces the same choice values, but with the moving costs reversed.

$$v_{0j}(a_j, n_{j,t-1}) = u(a_j, n_{j,t}) + c_j + \beta V(a_j, n_{j,t}) \tag{8a}$$

$$v_{00} = u_0 + \beta V_0 = 0 \tag{8b}$$

The outside population also receives an idiosyncratic preference shock for neighborhood j, resulting in expressions of the same form as 6 and 7, but with the moving costs reversed relative to originating in j. The total market population is denoted N.

4.2 Equilibrium in the Neighborhood

The utility flow of the neighborhood is an endogenous object. That is, the utility $u(a_j, n_j)$ that guides a household's choice is dependent on how many households are making the choice. Let $\hat{n}$ denote the population the household *believes* will be obtained in the neighborhood in period t. The choice value is (after dropping subscripts for legibility)

$$v_j(a, \hat{n}) = u(a, \hat{n}) + \beta V(a, \hat{n}) \tag{9}$$

This will produce a population flow, resulting in a delivered population n', according the choice probabilities it will induce.[2]

$$n' = \sigma_{jj}(\hat{n})n + \sigma_{0j}(\hat{n})(N - n) \tag{10}$$

Notice that $\hat{n}$ is an argument to the choice probability because it is an argument to the value function. An equilibrium is obtained by the usual means–when population induced achieves the population expected:

$$n^* = \sigma_{jj}(n^*)n + \sigma_{0j}(n^*)(N - n) \tag{11}$$

Figure 11 exhibits the equilibrium for two examples of the utility function and one value of initial population, n. For simplicity, here we are setting a time horizon of $T = 1$, so that $V = 0$. (The two utility cases appear to deliver similar results, but as we will show, the dynamics of the tqo cases diverge as the horizon of the household increases.) An intersection of the diagonal is an equilibrium. Expected populations off the diagonal are not equilibrium because they produce populations higher than expected or less than expected.

Note that equation 11 features both history and expectations. History matters because moving costs cause population to move sluggishly, so the population entering the period affects the population that will be obtained. Expectations matter because the household's

[2]All households have the same belief concerning the neighborhood's population.

Figure 11: Equilibrium Determination in the Neighborhood

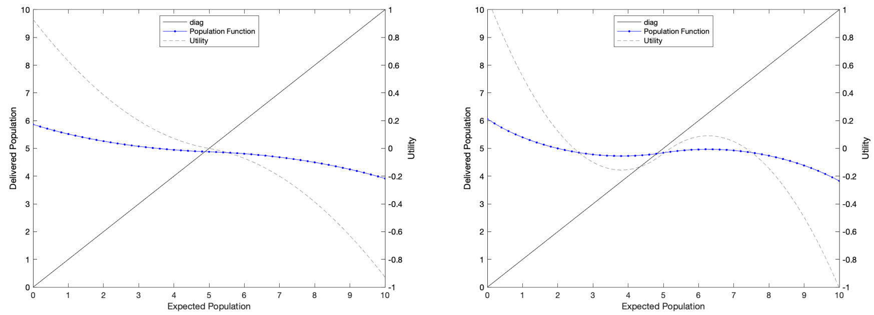
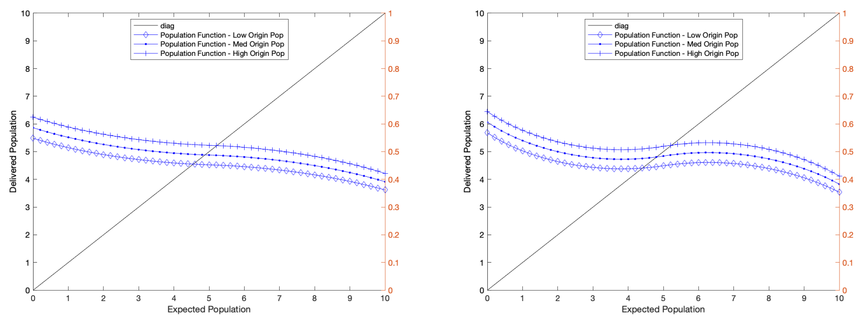


Figure 12: Equilibrium Determination in the Neighborhood for Multiple Starting Populations

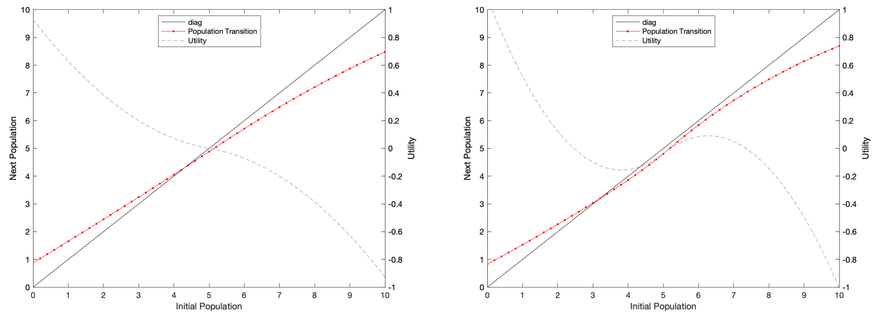


belief about the next-period population will affect their choice probability. And they matter together: Because the final population becomes next period's history, the equilibrium in one period depends upon the equilibrium in the last in a path-dependent way.

To demonstrate this property, Figure 12 plots the expected-to-delivered population for three different values of the neighborhood's initial population. Though a given level of expected population, $\hat{n}$, will yield the same expected utility and continuation values, the population delivered is affected by the number of households beginning the period in the neighborhood. Mathematically, the starting population acts as a weight in equation (10).Therefore, different values of n will result in different equilibrium population values.

These equilibrium correspondences of $n' = \sigma(n')n$, as depicted in the figure, form a mapping that characterizes population transitions from one period to the next. For intuition, consider drawing an infinite number of lines in Figure 12, and connecting the locus of their intersections with the diagonal. That correspondence of initial population n to next period's

Figure 13: Population Transitions



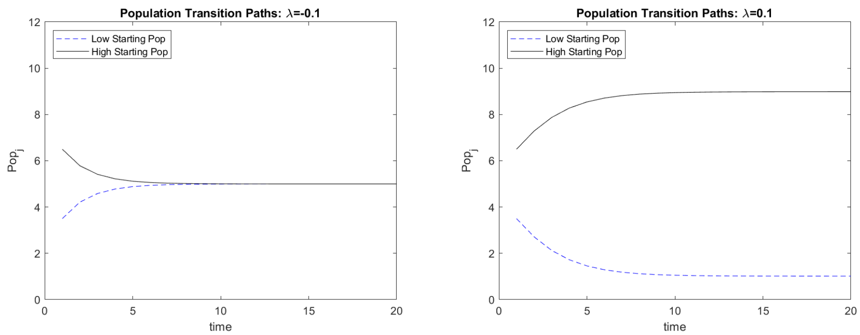
In appendix B, we show that in order to have 2 steady states, a necessary condition is for the utility function with respect to population to be increasing in some range in the support of n.

equilibrium n' yields the *population transition function* as drawn in Figure 13. All points are equilibria for the initial value of n, and here an intersection of the diagonal is now a steady state in the neighborhood.

The population transition function allows the model to characterize the time path of population in a neighborhood–which ultimately can be taken to the data of population dynamics in neighborhoods. For illustration, the lefthand plot Figure 14 displays the time path of population for two different starting values in each of the utility function cases. The dynamics work out by following the transition function from 13. Starting at an initial value of n_1 below the steady state value, the transition function function yields the next periods equilibrium population $n_2(\sigma(n_2), n_1)$, which becomes the initial population for the next period, $n_3(\sigma(n_3), n_2)$, and so on. Population changes converge to zero as the neighborhood reaches the steady state, $n_{ss}(\sigma(n_{ss}), n_{ss}) = n_{ss}$. The dynamics from above the steady state are conversely similar.

Thus far, we have illustrated the one period horizon version of the model, but having seen the model's properties, we now consider the importance of the forward-looking nature of the dynamic problem. The moving frictions make n a state variable in the household's problem: Population today matters for the value of the neighborhood tomorrow because it will affect which equilibrium can be obtained. As the horizon of the household increases, the population

Figure 14: *Population Transition Time Series*



becomes increasingly more valuable (positively or negatively). Figure 15 shows the equilibrium correspondence and the population transition functions that result from the problem with an increasing horizon. Comparing the left and right plots, something interesting occurs between the utility cases. With congestion effects only, the long horizon population transition function shifts upward in a nearly uniform way, reflecting the fact that the equilibrium population tends toward the center (the equilibrium correspondence from Figure 12 is flatter than the diagonal). With agglomeration, however, utility can be higher within a low region of population and within a high region. Incorporating (via present discounted value) the possibility of reaching these two regions, the population transition function features *two* steady states.[3]. Multiple steady states splits the neighborhood's population dynamics into multiple basins of attraction. This can be seen in the dynamics of the righthand plot in 14. This feature will figure prominently in our analysis below as shocks to amenities drive population shifts over time.

4.3 Innovations to Amenities and Expected Values

Up to now, amenities have been treated as known and constant, but we are interested in innovations to a–indeed, the shock of a planned highway route is a central theme of our study. We now consider the possibility of innovations to amenities and the expected value

[3]There is actually a third steady state in the center of the figure, but it is locally unstable, so we ignore these in our empirical exercises.

Figure 15: Population Transitions

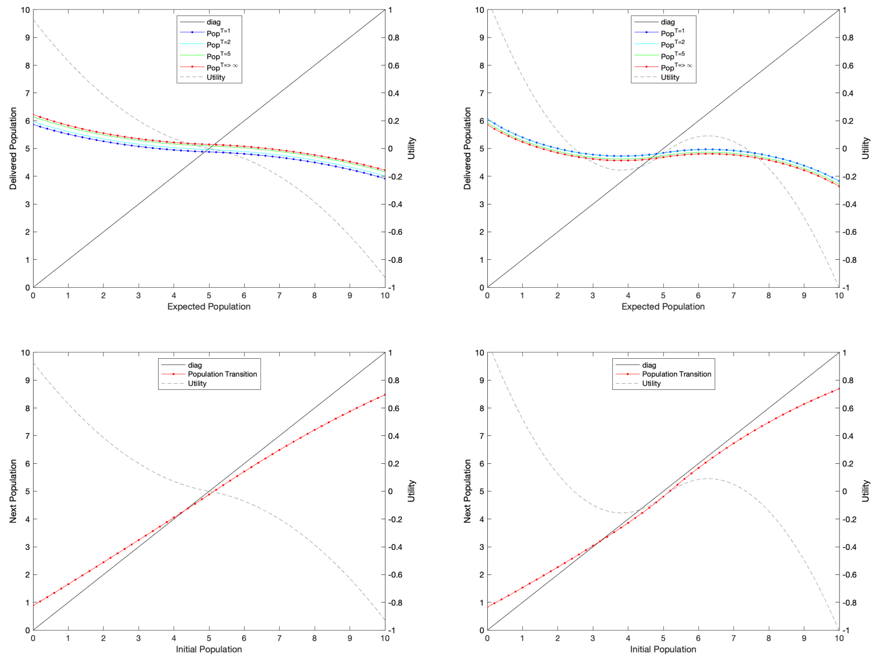
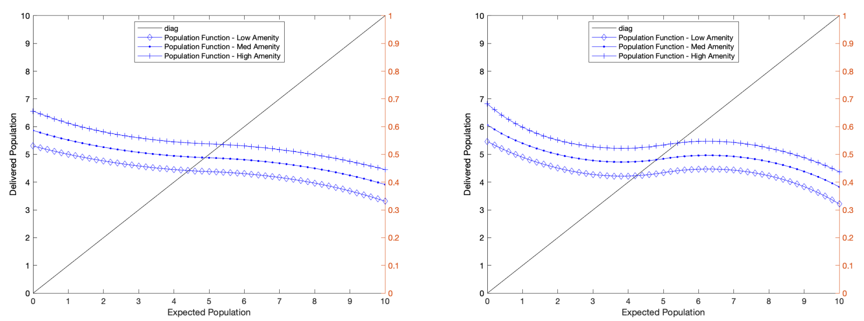


Figure 16: Equilibrium Determination in the Neighborhood for Multiple Amenities



problem that results.

First note that the level of the amenity will affect which equilibrium will be obtained, even under perfect certainty. This is for an obvious reason: for all else equal with respect to the endogenous amenity and origin population size, a neighborhood with better amenities offers higher flow utility and therefore reach a higher population size. Figure 16 exhibits the equilibrium for different levels of a (with no uncertainty). The higher the amenity, the higher the equilibrium population that can be supported.

We want to consider cases when amenities are subject to shocks, and consequently, households are subject to uncertainty about the neighborhood's amenities. To implement this, we introduce a timing assumption. Amenities are known when entering the period (whereas population is not), but may evolve in the future according to a known distribution, $a_t = f(a|a_{t-1}, \nu)$. The amenity can exhibit persistence, so the lag amenity level is an argument of the f function, as well as parameters ν. Equation 4 becomes an expected value function by integrating over states $a_{j,t+1}$

$$v_j(a_{j,t}, n_{j,t-1}) = u(a_{j,t}, n_{j,t}) + \beta \mathbb{E}V(a_{j,t+1}, n_{j,t}|a_{j,t}) \tag{12}$$

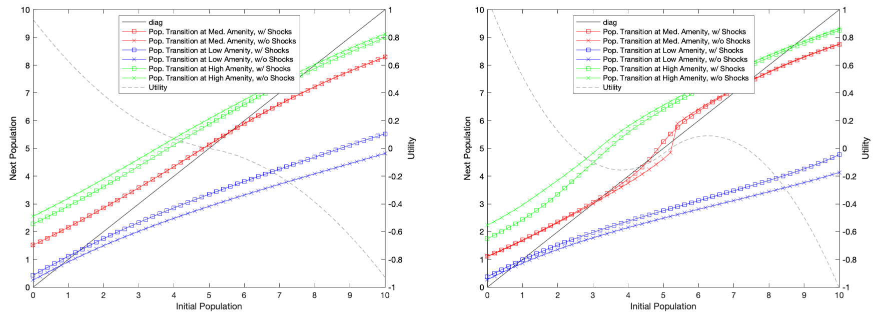
where

$$\mathbb{E}V(a_{j,t+1}, n_{j,t}|a_{j,t}) = \int \Big(\ln[exp(v_j(a_{j,t+1}, n_{j,t}) + exp(v_0)]\Big) f(a|a_{t-1}, \nu) da_{j,t+1} \tag{13}$$

Notice that $n_{j,t}$, which is determined in equilibrium, is an argument of the expected value function. Households solve 12 to arrive at choice probabilities, which then yield, via (10), an equilibrium when using the expected value function to make choices. This implies that amenities and population can interact (in nonlinear ways) to form the value of some pair of states, a, n. Expectations and uncertainty can affect the current equilibrium population, which will affect the future population, which will affect the current population, and so on. The recursive formulation of the dynamic program lets the model account for the infinite regress in a tractable way, but the point remains: Prospects for the future will affect the outcome that obtains in the present.

Figure 18 illustrates the effect of adding uncertainty about amenities to the model. The plot displays the population transition function for three amenity values–low, medium and high–with and without uncertainty. Two differences emerge. First, the values low and high amenity situations are mitigated when there is uncertainty–a bad shock has some chance of mean-reverting, and hence is not so lowly valued as when it is expected to remain forever. This feature is evident in either utility case. Second, the uncertainty smooths the jumps

Figure 17: Equilibrium Determination in the Neighborhood for Uncertain Amenities



apparent in the equilibrium rules, because again, the value of any amenity level is diffused by the uncertainty, making the value function a moving average rather than a step function. This latter feature is evident only in the case of agglomeration in utility, where multiple equilibria are possible.

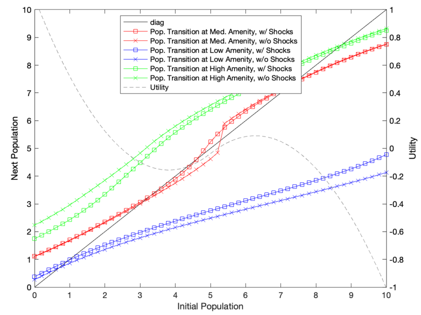
4.4 Population Dynamics

While much of the model is conceptual, the population dynamics it generates are in principle observable. We now discuss how the equilibrium correspondences produce population dynamics in the neighborhood from one period to the next.

Recall two key features of the model: first, some cases of the utility function were capable of producing multiple steady states, and second, amenities shift the equilibrium correspondences up and down. This latter feature matters for the transition function, because shifts in amenity levels can create or remove the possibility of multiple steady states. In particular, shocks to a neighborhood may move a neighborhood to a different basin of attraction.

Consider a case where a neighborhood receives a negative amenity shock. We focus on a shock large enough to disallows the upper steady state in utility cases with more than one steady state population. In Figure 18, this is represented by a shift of the curve from medium to low amenity. In both utility cases, this causes a decline in population. If the negative shock persists, the neighborhood reaches a new, lower steady state population. This new steady state is more starkly below the old steady state in the case of agglomeration in utility,

Figure 18: Equilibrium Determination in the Neighborhood for Uncertain Amenities



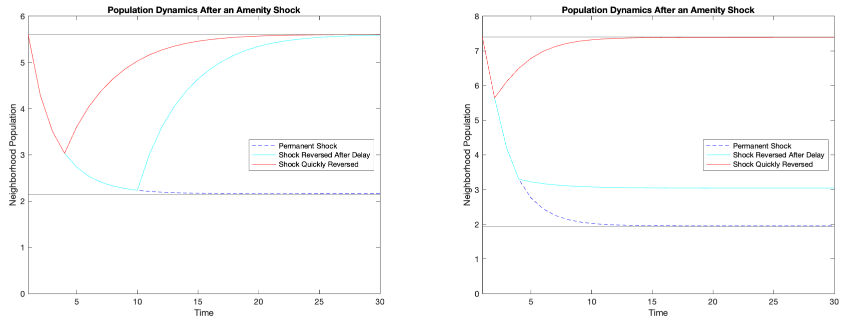
because the shock has bumped the neighborhood into a new basin of attraction, sliding to the lower of the two possible steady states. (A smaller shock could reduce the population but still obtained the higher of two possible steady states.)

Further consider, however, a neighborhood that receives a negative shock but actually reverts to its pre-announcement level of amenities. The population dynamics would be drawn according to the red line for a period of time, and then mid-transition, the dynamics would return to drawing from the blue line.

Will the neighborhood return to its initial steady state? It depends on how far the transition has progressed. If the shock is cancelled early enough that the neighborhood did not transition past the critical threshold (the discontinuity on the blue line in the transition function), the neighborhood is in the basin of attraction of the high steady state and will revert there. This time series is seen the in "zig-zag" blue dotted line in the time series plot on the right.

However, if, at the time of reversion, the population has crossed the critical threshold of its basin of attraction, even after the shock reverses, the population will move to the lower steady state. The lower steady state of the normal amenity (blue line on the left plot) is higher than the steady state of the negative amenity (red line on the left plot), but still below the initial high steady state. This is seen in the center, red dashed line on the righthand plot of population times series. The higher steady state is theoretically achievable under the normal amenity level, but having progressed to such a low population during the negative

Figure 19: *Population Transition After a Negative Shock*



shock phase, the neighborhood will not return.

These population dynamics convey two messages. First, a perceived negative shock can have lasting effects on a neighborhood, depending on the severity of the shock and the length of time the neighborhood lives under its perception. Second, the differential dynamics between the two utility cases gives clues to how one can estimate the underlying utility function.

5 Model Estimation (in progress)

This section describes the estimation of the model. The parameters of interest governing the shape of the utility function. Several other parameters are calibrated outside the model. First we describe how the simulation procedure produces a hypothetical history of neighborhood change.

5.1 Simulation Procedure

Estimation relies on simulation of the model under a path of history mimicking the evolution of the interstate highway system in U.S. central cities.

The simulated economy consists of N neighborhoods. A subset of neighborhoods ($\frac{1}{3}N$) is designated as control. The remainder enter a highway construction regime in which, in any given period, households believe a highway may arrive with probability π_h. If one arrives, the neighborhood incurs a utility negative penalty h for the next period and every period thereafter (i.e., constructed highway is an absorbing state). If it does not, the neighborhood remains in the construction regime. Households know when their neighborhood enters the regime and the penalty if a highway arrives. Yet, the highways actually arrive with probability $\pi_h^a < \pi_h$, meaning households overstate the probability that their neighborhood will receive the highway. This period corresponds to the late 1950s-1960s, in which highway plans were known, expected to be constructed, and did in fact start to arrive.

After a period of time T_1, highway plans are perceived to become less likely. If a highway has not yet arrived, the probability of transition falls to $a\pi_h$, $0 < a < 1$. Households know when they have entered the less likely construction regime. This period corresponds to the late 1960s and early 1970s, when highways began to see serious opposition.

After another period of time T_2, unbuilt highways are cancelled. At this point, a neighborhood under the construction plan but without a highway reverts to the pre-construction regime. This era corresponds to the period after 1973 when most remaining highway plans were cancelled.

The simulation continues for another period of time, T_3, to correspond to the period of observation available in our data, and possibly reflecting echo effects of having gone through the highway construction (and in some cases, completion) phase.

All throughout the simulation period, other shocks to utility may arrive, drawn from a distribution $F_a(0, \sigma^s)$. Shocks decay at a rate δ, so the law of motion for local amenities is $a_t = \delta a_{t-1} + \epsilon$, where $\epsilon \sim F()$. Households observe the shocks and know their distribution and persistence.

For each simulation, we solve the value and policy functions specified by the model. There is a value/policy function pair for each regime under a given guess of parameters. These policy functions then give the population dynamics for the neighborhood, resulting in a population history for a set of shocks passed through a regime history.

The neighborhoods are simulated for a long period of time before reaching the starting of the DGP simulation so that they can represent the long run ergodic distribution of neighborhood size.

5.2 Estimated Parameters

The main parameters of interest are those determining the shape of the utility function. Two other important parameters are the dispersion of amenity shocks σ and their persistence δ. Then, within the utility function, we use a combination of basis functions with linear coefficients:

$$u(p_j) = \alpha_0 + \alpha_1 p_j + \alpha_2 p_j^{\frac{1}{2}} + \alpha_3 p_j^{\frac{3}{2}}$$

This function has a location (constant) term, a linear term, a concave term, and a convex term. The linear combination of these basis functions is quite flexible and can generate as many as two "turns" in the derivative (changes in its sign). In practice, we derive the parameters from specifying 4 values of u at 4 points in the support of p, which allows us greater control in the shape of $u(p)$ to avoid wasting computation time in unreasonable areas of the parameter space.

Note that this is *net* utility with respect to population density. It could be composed of a combination of agglomerative and congestive factors. On the agglomeration side, examples include the presence of and variety of retail and public goods sharing. On the congestion side, factors affecting utility include traffic, noise, and of course, housing rents. The hypothesized function, with its flexibility in shape, can generate the race between these terms at various points in the support of population density.

5.3 Calibrated Parameters

Several parameters are calibrated outside the simulation loop. These include:

- Discount rate, $\beta = 0.95$.

- Move cost
  - Calibrated based on 1960 Census Tenure in Household
  - 1 year implied move probability from (interval censored-)exponential hazard model
  - $\approx 10.5\%$ annually; $c \approx -2.14$
- Scale parameter in logit choice
  - Calibrated using gross in and out mobility from 1950 SEAs
  - Holds fixed move cost
  - Derives implicit local quality from net migration
  - Matches average total gross mobility via least squares
  - $\gamma =\approx 2.3$
- Highway penalty, $h = -2\sigma$.
- Perceived highway probability, $\pi_h = 0.5$ and its reduction, $a = 0.5$.
  - This produces a half life of near certainty that a highway will arrive within ten years.
  - Actual highway arrival probability, $\pi_h^a = 0.06$.
  - This matches the average arrival rate of highways in the data.
- Time periods covering the highway regimes
  - $T_1 = 15$.
  - $T_2 = 5$.
  - $T_3 = 30$.

5.4 Matching Simulations to Data

The simulation procedure generates a set of histories that correspond to the treatment arms - NP, PNB, B. A given simulation produces an average population change, by treatment status, that is produced by the vector of parameters used to generate the population data. The targeted moments are the treatment-conditional population mean population In this way, the simulation seeks parameters that generates dynamic treatment effect that most closely match that of the data.

The model predicts change in population to compare with data,

$$\Delta_p(\theta) = [p_t - p_{t-10}] - [\tilde{p}_t(\theta) - \tilde{p}_{t-10}(\theta)]$$

where $\theta = (\delta, \sigma, \alpha_0, \alpha_1, \alpha_2, \alpha_3)$

Using the differences by initial population density bin q by treatment arm

$$r_{qth}(\theta) = \frac{1}{N^{p_q}} \sum_{p_q} \Delta_p(\theta)\mathbf{I}(h_t) * \mathbf{I}(p_q))$$

We are using the average for the treatment arm, so that q simply represents the mean (although finer moments may be possible). For decades 1950s to 2010s, with 3 treatment arms (2 treated, 1 control), this is $24 \times q (= 8 \times 3 \times q)$ to match. The residuals to minimize are:

$$M(\theta) = \sum_t \sum_h \sum_q r^2_{qth}(\theta)$$

5.5 Illustration of Identification

Because all parameters can affect the shape of the population dynamics, a global solution of the value and policy functions is necessary. Estimation proceeds through an iterative grid search, simulating the model for successively narrowing bands of the parameter space.

What features does the model need to generate population decline, and *persistent* population declines? First, it needs 2 steady states, which arises out of $[u(p)]$, as argued earlier. Then, the highway penalty must be salient, so that a highway shock could put a nontrivial number of neighborhoods into the lower steady state. This comes from the size of the shock and length of the highway construction regime. Finally, neighborhoods that do transition to the lower steady state needs minimal "escape" probability thereafter, which pertains to the combination of $[u(p), \sigma, \delta]$.

To illustrate how identification works, we simulate hundred of parameter combinations and plot the treatment effects–the mean difference in population of P and PNB to NP–generated by the highway regime. We plot these treatment effects, which correspond to our moment condition above, for candidate utility functions that have only net congestion or have a regime with net agglomeration.

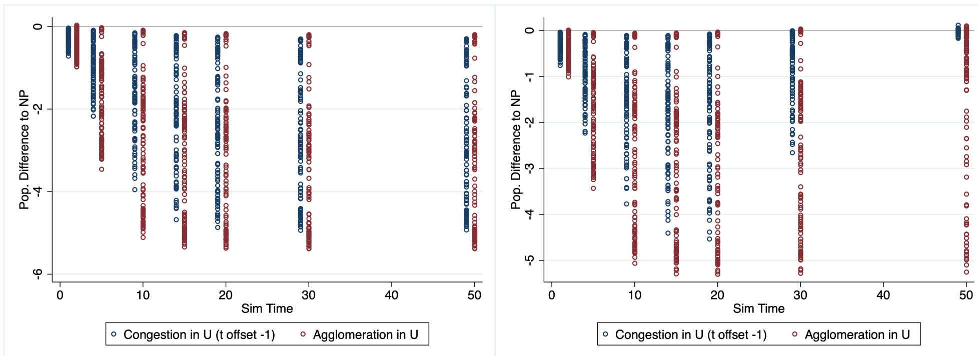
Figure 20 shows the results for B on the left and PNB on the right. Each dot corresponds to the moment (average population difference) for a single simulation (i.e., a specific vector of parameters). For B, in neighborhoods where highways actually do arrive, the average effect on population is negative, as expected. For PNB, when utility has only congestive forces, the highway regime reduces their population, but it recovers after cancellation. However, when utility has some region of agglomeration, it is *possible* to get persistent negative effects on population even after cancellation. Not every parameter combination will produces the persistent effects, as seen by the plots that still recover to their previous average. But it is possible when net agglomeration is present, whereas it is not seen at all when there is only congestion.

6 Conclusions

We analyzed the role of self-fulfilling expectations in determining urban spatial structure. An expected large negative shock to neighborhood amenity can cause permanent decline, even

Figure 20: *Simulated Average Population of Treatment Arm, by Class of Utility Function*

Built **Planned, Not Built**



NOTES: The figure plots the average population, realtive to the untreated (Not Planned) neighborhood category, at various time frequencies. Each dot represents one simulated path for a vector of parameters. The highway plan is canceled at $t = 20$.

if the shock is never realized. This result is consistent with forward-looking behavior and strong economies of density in residential location choice. Our results open the possibility that spatial structure may not be uniquely determined, even conditioned on nature and history. Instead, self-fulfilling expectations can shape city structure.

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A Appendix

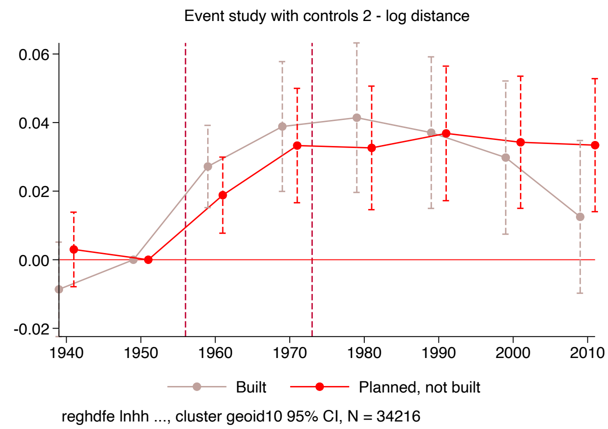


Figure A.1: Spatial treatment

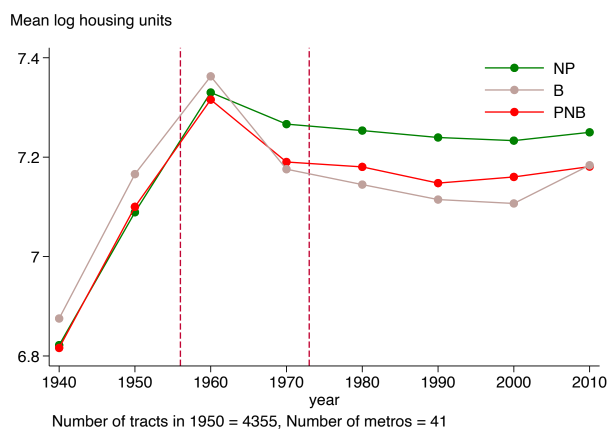
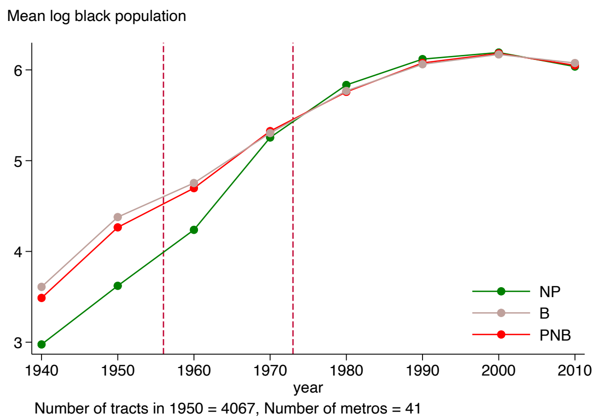
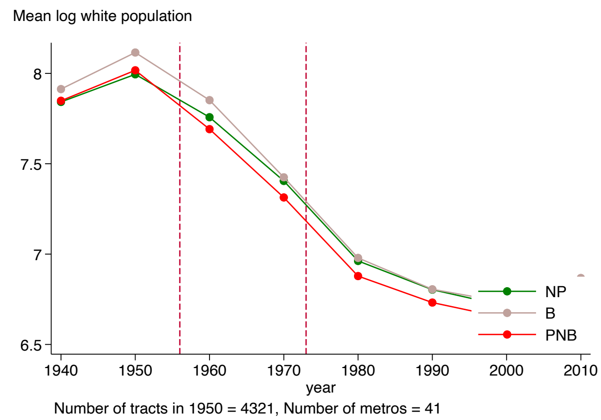


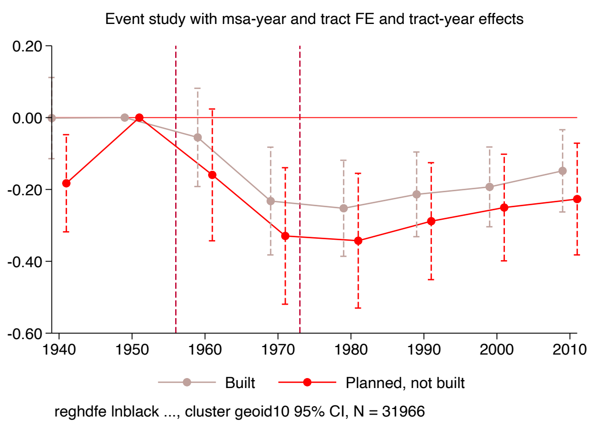
Figure A.2: Housing units



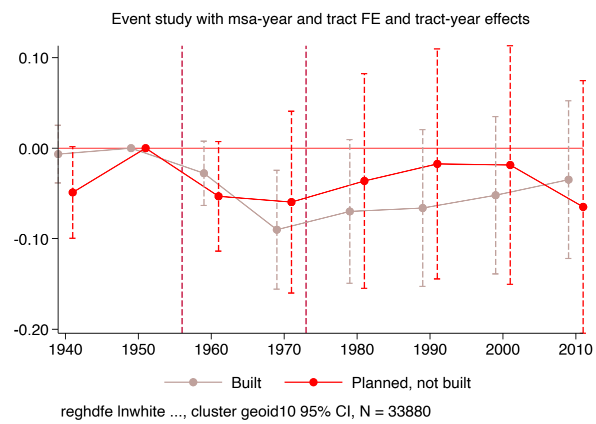
(a) Log Black population



(b) Log white population



(c) Event study, log Black population



(d) Event study, log white population

Figure A.3: Race

B Steady States

Preliminaries

Let P be a function mapping the neighborhood's population from period t to $t+1$.

$$P(v, p_t) = p_{t+1}$$

With the 2 location ("here, there") environment, the function is the sum of stayers in the neighborhood plus inflows from outside.

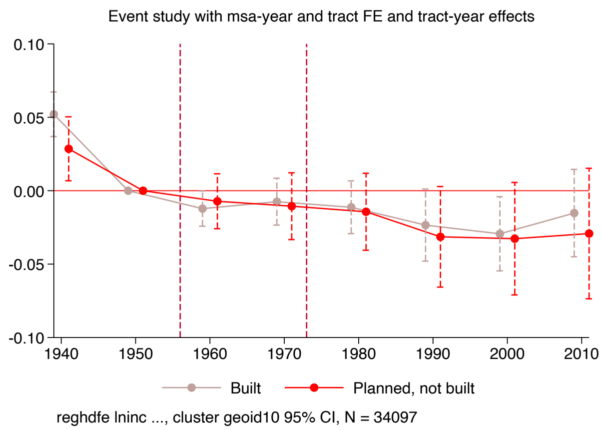


Figure A.4: Average household income

$$P(v, p_t) = \sigma_1(v_1)p_1 + \sigma_0(v_0)p_o$$

The values and choice probabilities are subscripted by the origin because of moving costs: inflows pay to move in, while outflows pay to exit.

To reach be at a steady state, the equation outcome is

$$p_{t+1} = p_t = \sigma_1(v_1)p_1 + \sigma_0(v_0)p_o$$

or, rearranged showing that in a steady state, outflows balance inflows:

$$\sigma_0(v_0)p_o - (1 - \sigma_1(v_1))p_1 = 0$$

Define $F(p_1) = \sigma_0(v_0)p_o + \sigma_1(v_1)p_1 - p_1$. We will study this equation as a function of focal neighborhood population when entering the period. The functions σ, v are also dependent on parameters, but we suppress that notation for now.

Equilibrium Population

Within a given period, the equilibrium population in the focal neighborhood is a function of that neighborhood's pre-existing population. Letting $\tilde{p}$ be the agents' expected population in the neighborhood and $\hat{p}$ be the resulting population, the mapping is

$$\hat{p}(\tilde{p}) = \sigma_1(v_1(\tilde{p})))p_1 + \sigma_0(v_0(\tilde{p}))p_o$$

An equilibrium obtains when the expected population returns that population,

$$p^* = \sigma_1(v_1(\tilde{p})))p_1 + \sigma_0(v_0(\tilde{p}))p_o \implies \tilde{p} = p^*$$

Define $p^*(p_1)$ as the locus of equilibrium populations delivered by starting with population p_1. Because $\sigma_1 \in [0,1]$ is a positive number, this is an increasing function of p_1. Intuitively, the more "home" population the focal neighborhood can contribute, the higher the equilibrium population that will result, ceteris paribus. (Visually, the correspondence $\hat{p}$ is shifted up by an increase in p_1.)

Making the equilibrium mapping explicit in our notation, the function of interest is

$$F(p_1) = \sigma_0(v_0(p^*(p_1))))p_o + \sigma_1(v_1(p^*(p_1)))p_1 - p_1$$

Number of Steady States

When does this model have multiple steady states? That is, when does the equation $F(p_1)$ have more than one solution?

To cross the horizontal axis more than once, the function F must be non-monotone, or equivalently, it must have a derivative that is nonpositive in some region(s) and nonnegative in other region(s). The derivative of F, using the chain rule, is

$$\frac{dF}{dp_1} = \frac{d\sigma_0}{dv_0}\frac{dv_0}{dp^*}\frac{dp^*}{dp_1}p_0 + \frac{d\sigma_1}{dv_1}\frac{dv_1}{dp^*}\frac{dp^*}{dp_1}p_1 + \sigma_1(v_1(p^*(p_1))) - 1$$

The derivative is hard to analyze in general, but a key point can be made: for there to be multiple steady states, the value function v cannot be monotone decreasing in p^*.

To see why, proceed by contradiction. Assume the value function is decreasing in p^*; that is, $\frac{dv_0}{dp^*} < 0, \frac{dv_1}{dp^*} < 0$. The choice probabilities, if of the logistic form, are increasing in v, so $\frac{d\sigma_0}{dv_0} > 0, \frac{d\sigma_1}{dv_1} > 0$. We have established that the equilibrium function is increasing in p_1, so $\frac{dp^*}{dp_1} > 0$. Therefore,

$$\underbrace{\frac{d\sigma_0}{dv_0}}_{>0}\underbrace{\frac{dv_0}{dp^*}}_{<0}\underbrace{\frac{dp^*}{dp_1}}_{>0} < 0$$

and

$$\underbrace{\frac{d\sigma_1}{dv_1}}_{>0}\underbrace{\frac{dv_1}{dp^*}}_{<0}\underbrace{\frac{dp^*}{dp_1}}_{>0} < 0$$

The populations p_0 and p_1 are nonnegative by definition. Finally, because $\sigma_1 \in [0, 1]$, the sum $\sigma_1(v_1(p^*(p_1))) - 1$ is nonpositive. Hence, $\frac{dF}{dp_1}$ is the sum of three negative numbers, meaning it is strictly negative, which contradicts the requirement for F to have multiple solutions. *QED*

This logic shows that nonmonotonicity in v is a necessary (but not sufficient) condition for there to be multiple steady states. Furthermore, by standard results in dynamic programming, if $u(p^*)$ is monotone decreasing, then $v(p^*)$ will be monotone decreasing as well. Hence, to have multiple steady states, $u(p^*)$ cannot be monotone decreasing.