

Unequal Access: Racial Segregation and the Distributional Impacts of Interstate Highways in Cities

Laura Weiwu*

University of California, Berkeley

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Abstract

This paper measures the Interstate Highway System's impact on welfare inequality in cities separately by race and education. I quantify the incidence of commute benefits from connecting residences to workplaces, costs where highways are built, and equilibrium responses using novel data on commuting and historical maps nationwide. Given the concentration of benefits in suburbs and costs in the urban core, differential suburbanization by race, more pronounced than by education, contributes to racial gaps in welfare gains. Using a spatial equilibrium framework, opening access to peripheral areas for minority families eliminates the majority of the gap while preserving aggregate welfare improvements.

JEL Classifications: N92, R13, R23, R41

Keywords: Infrastructure, segregation, inequality

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1 Introduction

Cities worldwide display stark differences in quality of life as access to public services and opportunity vary widely between neighborhoods segregated by socioeconomic status. With the rapid rise in urbanization globally, inequality within cities has become progressively more important for inequality overall (Beall et al., 2011). Transportation infrastructure is a broadly relied upon tool for economic development by connecting places to employment and economic prospects, but locally, it imposes negative environmental and social costs. The extent to which infrastructure reduces or worsens inequality depends crucially on how these benefits and costs are shared across groups.

In the U.S., the Interstate Highway System (IHS) continues to be the largest transportation and public works project, with investment exceeding \$500 billion in 2020 dollars.¹ Funded by the Federal-Aid Highway Act of 1956, it marked an unparalleled national push to develop infrastructure as 90% of the financing was from the federal government. The most intensive building phase between 1960 and 1970 added over 25,000 miles of highways and permanently reshaped cities through two main channels: faster commuting from residences to workplaces, and negative harms by routes such as heightened pollution, traffic, and the physical barrier of highways.

This paper employs a spatial equilibrium framework to quantify which groups receive the benefits, bear the costs, and are affected by equilibrium responses to the IHS, separately by race and education. Before this analysis, a few simple facts already suggest the welfare impacts were unequal, particularly by race. From 1960 to 1970, levels of racial segregation peaked as the Civil Rights Act of 1968 had not yet effectively lowered housing discrimination (Cutler et al. 1999). Minority households were more likely than White households to reside in the urban core, where commute benefits were more muted with jobs mostly downtown and where highways intersected, before and after Interstate development (Caro 1974, Jackson 1985, Rose 1990). They were also less likely to commute via automobile.

While these patterns are informative for the distributional impacts, open questions remain on whether race vs. economic differences are more central, which mechanisms are the key contributors, and the magnitude of the rise in welfare inequality from the IHS. This paper leverages new data to address these questions and advance the literature in three main ways.

First, is improving the measurement of the primary benefit of highways: reducing commute costs. Using restricted microdata from the 1960–1970 Journey to Work surveys of the Census, this study builds commute flows disaggregated by race and education across 25 major U.S. metro areas (CBSAs) and significantly expands on previous work focused on Chicago and Detroit (Brinkman and Lin 2022, Bagagli 2024). This prior research does not have socioeconomic traits in the com-

¹The original cost of the system was \$114 billion, equivalent to roughly \$500 billion today. Investment in highways has continued, including the \$110 billion allocated by the Infrastructure Investment and Jobs Act of 2021 for roads, bridges, and surface transportation.

muting data, making it more suited for aggregate analysis, while the microdata contain rich individual characteristics necessary to understand *inequality*. Yet, even within the Census data, *travel time* is not available until 1980, so changes in neighborhood time to workplaces are calculated from newly digitized historical maps for 71 metro areas that cover 49 million tract-to-tract pairs.

Second, transportation infrastructure is a multifaceted policy with myriad equilibrium consequences, and existing studies on the Interstates each consider a subset of factors. This paper presents a *unifying framework* to separate multiple mechanisms behind unequal incidence. Like [Brinkman and Lin \(2022\)](#), this study estimates local disamenity costs concentrated downtown where roads intersected. Combined with improved connectivity in the suburbs, these two effects lead to migration outwards i.e. suburbanization. Beyond aggregate population responses, which are also the focus of [Baum-Snow \(2007\)](#), I document substantial heterogeneity in migration by race, with less variation by education within race. Similar to [Mahajan \(2024\)](#) and [Bagagli \(2024\)](#), this paper examines how disamenities, income differences, and racial homophily contribute to increased racial segregation from highways. They omit other factors which the disaggregated Census data capture, such as public transit use that differs substantially by race and education across routes, and firm location that is group-specific and can change with highways (as in [Miller 2023](#)).

Third, the historical narrative has pointed to an *alternative mechanism* for low Black suburbanization rates from Interstate development: discrimination by race prevalent in suburban neighborhoods. While previous work models sorting as a result of residential choice (e.g. [Bayer et al. 2007](#)), this paper demonstrates that barriers to choice play an outsize role in the neighborhood locations of minority households. Further, they *interact* with place-based policies, such as infrastructure, to create unequal policy impacts.² These barriers are proxied using maps created by the Home Owners' Loan Corporation (HOLC) in 1932 to indicate high credit risk and racially integrated "redlined" areas, often located in city centers. As [Fishback et al. \(2020, 2022\)](#) note, HOLC followed existing segregation patterns rather than necessarily creating them. Still, these patterns may have reflected informal discrimination since outside redlined areas, Black families faced landlords and property owners who resisted integration e.g. by including racial covenants to restrict home sales to only White households ([Rothstein, 2017](#)).³

In the empirical analysis to follow, I rule out other explanations besides discrimination as fully explaining racial differences in residential sorting from highways, including income, transit usage, and place of work. Within the microdata, all variables are cross-tabulated by race (White/Non-White, primarily Black in 1960) and *education* (less than high school/high school+) rather than *in-*

²Recent experimental studies by [Christensen and Timmins \(2022, 2023\)](#) show that housing discrimination leads to welfare losses and is a determinant of neighborhood choice. This study focuses on an observational, rather than experimental, setting that occurs during a period when discrimination was more pervasive.

³Though ruled unenforceable by *Shelley v. Kraemer* in 1948, these covenants continued to appear in property records until 1955 in Minnesota. The "Fair Housing" Civil Rights Act of 1968 outlawed these practices nationally.

come as income can rise endogenously with improved workplace connections. Summary statistics show that higher-educated Black households have similar weekly earnings, rents, and home values (\$500, \$460, \$92k) as less-educated White households (\$570, \$440, \$94k) while higher-educated White households average much higher (\$730, \$610, \$130k). Comparing the migration of these three groups then informs whether education/economic differences or race is the key mediator for differential sorting.

I employ a difference-in-differences strategy using variation across census tracts within metro areas that differ by intensity of treatment from Interstate segments built between 1960 and 1970 (including CBSA fixed effects). Changes in population levels are measured against changes in Commuter Market Access (CMA). CMA summarizes infrastructure impacts and is micro-founded by the general equilibrium model, which builds on existing work by [Ahlfeldt et al. \(2015\)](#), [Donaldson and Hornbeck \(2016\)](#), and [Tsivanidis \(2023\)](#) to consider a within-city context with commuting. It aggregates over (a) *commuting costs* which, exploiting the microdata, embeds differential public transit use by group and route, and (b) *workplace wages and employment* by race and education, capturing how the location of good jobs differs by group. Interstate development directly raises CMA by lowering travel costs for commuting via car.

The results show that within White households across education, there is no significant difference in migration to CMA improvements despite large economic gaps between the two groups. Higher-educated Black versus less-educated White households, despite economic similarities, show statistically different migration responses. Further ruling out that economic differences are the primary driver, controlling for changes in rent, e.g., from the suburbs becoming higher rent, does not affect the results by race. Notably, the Black CMA coefficient is not just lower than for Whites but often indistinguishable from zero. I also find that migration away from neighborhoods immediately by highways and their disamenities follows a similar pattern. In summary, low Black responsiveness to highway impacts cannot be explained by economic, mode of transport, or workplace variables alone, and an alternative mechanism remains.

As suggestive evidence for discrimination as a factor, I measure Black responses to CMA within redlined areas, and population changes are no longer zero and are significantly positive.⁴ The limited response previously to CMA improvements, which are greater in the suburbs, may then result from barriers that inhibit free movement to the suburbs. However, racial homophily is not yet ruled out since preferences to be with same-race families can lead Black families to remain in integrated redlined areas. In the model section, I estimate linear parameters for racial homophily that show White homophily is greater than Black homophily, and this social preference is not

⁴While racial covenants were in place across the U.S., existing records of covenants are currently only available in the Minneapolis-St. Paul metropolitan area. The specification is underpowered when using observations for a single metro area, so the empirical test focuses on redlining maps instead, which are available for the whole country.

quantitatively large enough to account for Black clustering in central, redlined areas. Additionally, controlling for changes in racial composition, i.e. that downtown areas become less White, does not substantially affect the low Black migration coefficient on CMA changes.

For these results, I develop an identification strategy to address the non-random placement of routes. Urban highway routing was influenced by political considerations, often leading to their location in socioeconomically disadvantaged and declining neighborhoods and thus the unequal incidence of their costs. Consequently, in estimation, OLS conflates selection with treatment effects. For cleaner comparisons, within the digitized historical maps, major roads are considered candidates for Interstate construction. Not all were converted, and the historic roads that remain form a natural control group. Covariates for the location of historical railroads, ports, canals, rivers, and the central business district are also included to create areas with similar propensity of receiving an Interstate road. Lastly, I construct two instruments by (1) drawing a Euclidean ray network to intersect intermediate cities where neighborhoods coincidentally between them are treated ([Chandra and Thompson, 2000](#)), and (2) digitizing for 100 cities planned engineering maps that were less subject to political influences. This paper cannot use instruments from past studies on city-level Interstate impacts, such as the national 1947 plan in [Baum-Snow \(2007\)](#) or exploration routes in [Duranton and Turner \(2012\)](#), as they are insufficiently granular for neighborhood (tract) outcomes.

Then, to pinpoint the Interstates' effects on migration rather than suburbanization already occurring, in all specifications, I control for distance from the central business district and exploit variation between suburbs connected by Interstates and other suburbs connected by comparison historical roads.⁵ Furthermore, I conduct the [Borusyak and Hull \(2023\)](#) method of re-centering against pre-existing market connectivity.

While the empirical analysis is transparent in its findings, it does not provide a framework for measuring how multiple forces simultaneously impact welfare, necessitating a more formal model. After Interstate highways raise commuting access and impose disamenities, migration in equilibrium changes several components in welfare such as housing prices, wages at firms, and endogenous amenities (as a function of racial composition, similar to [Diamond 2016](#)). Moreover, *counterfactual* questions cannot be answered absent a model, which can simulate removing each channel to measure their role in welfare. For example, while the empirical results indicate there is differential migration, possibly due to discrimination, they do not quantify the size of the contribution to inequality. Consequently, in the second section of the paper, I parameterize the model and employ it to separate the mechanisms behind welfare gains.

In model estimation, I leverage the Interstate shock in a theory-consistent way for several esti-

⁵Increasing crime in the central city, desegregation of school districts, the Great Migration, and subsidies for suburban development were parallel contributors to suburbanization ([Jackson, 1985](#); [Cullen and Levitt, 1999](#); [Boustan, 2010](#); [Baum-Snow and Lutz, 2011](#); [Boustan, 2012](#)).

mating equations. After running a gravity equation of commuting, changes in CMA are measured, which then provide variation for a key parameter behind segregation—racial homophily. I construct instruments for racial composition following [Davis et al. \(2019\)](#) by simulating how race-specific mobility to the CMA Interstate shock implies percent White is declining in parts of the urban core. Importantly, estimation of homophily employs variation within redlined areas, which are already racially integrated, to avoid conflating preferences with barriers. As noted earlier, I find that racial preferences are greater for the White population compared to the Black population. Additionally, I estimate highway costs as the decline in amenities by highways, which are reflected in migration/price changes, through a revealed preference approach.

Using the estimated parameters and additional calibrated ones, in the general equilibrium framework, development of Interstate highways changes welfare by -1.5%, -0.2%, 2.7%, and 3.0% for less-educated Black, higher-educated Black, less-educated White, and higher-White households, respectively. Commute cost reductions constitute most of the gains, so properly measuring changes in network connectivity using the data developed in this study is central to policy evaluation. As is evident, the race gap is substantially larger than the education gap within race, and the IHS widened racial inequality. Importantly, these values are *within-city* estimates of welfare impacts and do not include more aggregate gains, which could alleviate the welfare losses for Black households. Previous research by [Michaels \(2008\)](#), [Duranton et al. \(2014\)](#), and [Allen and Arkolakis \(2022\)](#) indicate that highways also improved trade across cities for certain sectors and aided regional economic development.

Breaking down the impacts further, the direct channels of commute benefits and disamenities alone lead to large welfare differences, as initially, Black families resided near Interstate routes and commuted with cars at a lower rate. Allowing for reallocation via migration increases racial inequality by 30% since White households suburbanize more and magnify their gains from road development. Equilibrium adjustments in wages, housing prices, and endogenous amenities are less significant and somewhat offset each other for welfare.

These estimates provide evidence on the distributional impacts of the Interstate system in cities, which have not yet been comprehensively quantified and are valuable in their own right, even without a strong stance on whether discrimination is involved.

Now turning to the role of discrimination, I classify neighborhood barriers as the difference between White and Black households in residential location, *after removing factors related to neighborhood choice* of housing prices, the location of good workplaces by group, mode of transport availability and use by group, and racial homophily. The model-implied location residual without these other components commonly corresponds to the fundamental amenity term in urban models.

I test whether this measure of barriers coincides with empirical proxies for discrimination using a border discontinuity design along borders in the redlining maps. As measured directly in the data,

there is an immense 140% increase in the Black population when entering redlined areas, and a still sizeable 50% decrease in the White population. These large population jumps are not fully explained by house price differences (a more modest 20% drop at the border), and adding additional socioeconomic controls only somewhat reduces the discontinuity. Given parameter estimates, the biggest factor behind White households not residing in integrated redlined neighborhoods is racial homophily, and this same-race preference also partially accounts for Black clustering on the redlined side. Notably, the fundamental amenity residual is smooth across the border for White households, indicating the identification assumption of similar characteristics at the border is satisfied.⁶ Yet, for Black households, a large residual remains, and the asymmetry across the two groups at the border is strongly suggestive of race-specific determinants.

These model-implied barriers play a large role in inequality in welfare impacts. After simulating opening neighborhood access in the spatial equilibrium framework by removing these barriers, which are especially large in the suburbs, the development of Interstate highways raises welfare levels of the Black population by 1%, and the racial gap in impacts closes by a substantial 54%. All groups benefit from highway development, and impacts for the White population remain the same, so gains for Black households do not lead to a zero-sum game for aggregate highway impacts. These results show how the limited mobility of disadvantaged groups can lead to unequal consequences from place-based policies, even if they are not inherently racially-targeted. In this setting of the Interstate highway system, reducing barriers to choice goes far in closing the gap.

2 Historical Context and Data on the Interstates and Inequality

In this section, I describe the context related to the Interstate highway system's impacts on cities and which data sources are needed for measurement.

There were several intended economic benefits that motivated highway development when the Federal-Aid Highway Act of 1956 was passed. The 42,800-mile road network, the largest in the world, would lower road congestion that was rising as a result of the ongoing relocation of families into the suburbs. Postwar programs encouraged residential migration outward and greater commuting to workplaces. For example, the GI Bill subsidized homeownership for millions of veterans, and the Federal Housing Act of 1949 expanded mortgage insurance for newly constructed suburbs while simultaneously funding the clearance of blighted downtown areas (Rose, 1990).

As commute cost reductions are a core impact of highways, precise measurement of the change in commute times is essential. However, travel time surveys were conducted sparsely in the period

⁶I remove physical barriers of large roads, railroads, and highways from the sample to only measure social barriers. I further drop areas near school district borders that may fall along the borders of redlining maps. Additionally, fundamental amenities often refer to natural amenities, and in robustness checks, land cover types of open water and wetlands are continuous along the border, supporting the identification assumption of no change in fundamental amenities.

of Interstate construction.⁷ I build commute time matrixes using Shell Atlases in 1951 and 1956 that I digitized for 71 cities (Rumsey, 2020). Road networks are categorized into superhighways and other major roads, and these two categories are assigned different speeds following historical surveys (Gibbons and Proctor, 1954; Walters, 1961). I assign each Interstate segment its posted speed limit (55–65 mph) and use the PR-511 database from Baum-Snow (2007) to exploit decade-by-decade variation in segment openings. Commute times are generated in ArcGIS Network Analyst by overlaying the Interstate and historical road networks. To incorporate commuting via public transit and other transport modes, I retrieve reported times by mode from the 1980 Decennial Census, the first census to survey travel time, and non-parametrically estimate times and mode shares by decade over bins of bilateral distance and distance from the central business district (CBD).

Beyond the benefits, the harms and inequities of highways were quickly evident as they displaced and polluted surrounding communities, often low-income ones targeted for urban renewal by city planners (Hirsch, 1983). In response, freeway revolts aimed to halt construction or shift the course of routes.⁸ Revolts were occasionally effective, though far less often when initiated by disadvantaged groups (Rose and Mohl, 2012).

To measure disparities in Interstate incidence, I collect the location of residences and workplaces separately by race and education from Decennial Censuses in 1960 and 1970. The decade in between covers 51% of network construction. Residential units are census tracts, and workplace units are Place of Work zones, which I constructed for this study as the intersection of county and municipality codes from the 1960 Census Journey to Work questionnaire. The sample is limited to 25 of the largest metro areas i.e. CBSAs, listed in Supp. Appendix Table G.26, as smaller ones have few Place of Work zones. In some specifications measuring residential changes, I expand the sample to 96 CBSAs using tract-level aggregates from IPUMS-NHGIS for the longer panel of 1940 to 1990 (Manson et al., 2017). Race is split into White and Non-White since finer cuts leave too few counts, where Non-White is treated equivalent to Black (which comprised almost all of the Non-White population in 1960).⁹ Education is split into high school graduates and those without a high school degree, approximately a 50-50 cut. For each group and geographic unit, I calculate average wages and quality-adjusted housing prices. Supp. Appendix G contains more details.

In Table 1, I display summary statistics for 1960, and Column 5 indicates which variables are

⁷Brinkman and Lin (2022) use travel surveys for Chicago and Detroit in 1953 and 1956, respectively. However, these surveys only report average times for aggregated commute flows and are not suitable for evaluating distributional impacts. They are also for years when few segments of Interstate highways were completed.

⁸A prominent example is the Lower Manhattan Expressway (I-78) which was shut down after advocacy by Jane Jacobs against metropolitan planner Robert Moses.

⁹In 1960, 11.4 percent of the population was Non-White and 10.5 percent of the population was Black (Census Bureau, 1961). Only 3.5% of the population was Hispanic (with Spanish origin surname) in 1960 and were enumerated under the White category as the Census did not ask respondents about ethnicity until 1980. Black households thus comprise almost all of the Non-White population.

newly available using the microdata, such as detailed neighborhood and commuting characteristics. Large differences are present by race *conditional on education*: 49% of Black higher-educated workers commute by car compared to 66% for White higher-educated workers, but conditional on car usage, the distance is similar. Among the higher educated, Black workers are located 3.6 miles closer to the CBD, where commuting improvements are muted, and reside 0.8-0.9 miles closer to a highway, which can be due to political influences leading to unequal route placement.

Are the racial differences in location explained by economic characteristics? As shown in Table 1, wages, rents, and home values of Black higher-educated workers are comparable to White less-educated workers. Yet, the two groups still experience substantial differences in location relative to highways and the central city, so wages/prices alone do not appear to be the largest explanatory factor (Bayer et al., 2021).

Table 1: Summary Statistics by Race and Education in 1960

Variables	(1) Black <HS	(2) Black HS Grad	(3) White <HS	(4) White HS Grad	(5) New Microdata
Economic Variables – Mean (SD)					
Weekly Wages (2010\$)	402.3 (115.6)	495.2 (131.6)	569.4 (97.6)	726.7 (159.1)	
Rent (2010\$)	382.9 (124.6)	464.6 (136.0)	444.9 (140.8)	607.7 (194.8)	
Home Value (2010\$)	65,900 (29,850)	92,200 (35,740)	93,700 (32,050)	130,000 (40,200)	
Home Ownership Rate	0.334 (0.238)	0.379 (0.273)	0.599 (0.266)	0.626 (0.280)	
Neighborhood Variables – Mean (SD)					
Pct HOLC D	0.661 (0.405)	0.554 (0.436)	0.303 (0.409)	0.189 (0.342)	✓
Dist to Highway (mi)	1.779 (4.072)	1.643 (3.753)	2.578 (4.891)	2.565 (4.781)	✓
Dist to CBD (mi)	6.187 (7.703)	6.337 (6.888)	9.743 (9.485)	9.892 (9.086)	✓
Commuting Variables – Mean (SD)					
Commute Time (min)	26.86 (11.07)	26.76 (10.75)	26.65 (12.03)	27.74 (12.42)	✓
Commute Dist (mi)	9.30 (7.38)	9.36 (7.03)	9.22 (7.20)	10.11 (7.25)	✓
Pct Auto	0.392 (0.324)	0.488 (0.361)	0.561 (0.315)	0.663 (0.293)	
Auto Commute Time (min)	28.56 (14.89)	28.27 (13.97)	28.02 (14.66)	28.31 (13.93)	✓
Auto Commute Dist (mi)	11.07 (7.56)	10.84 (7.34)	10.56 (7.38)	10.68 (7.19)	✓
Rounded Count	N=2,834,000	N=1,334,000	N=16,190,000	N=18,240,000	

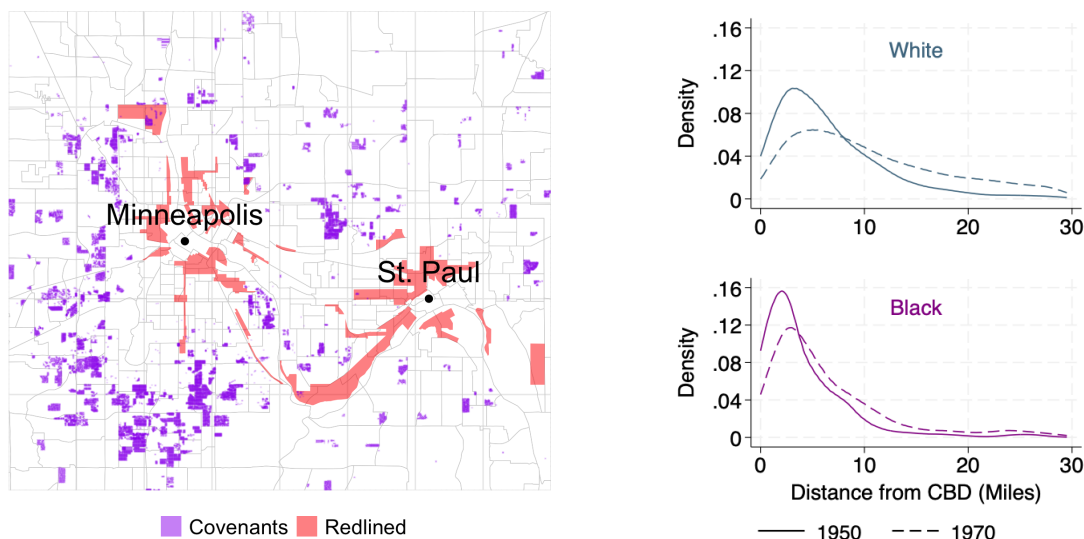
Notes: Data from the 1960 Census restricted microdata. Weekly wages are for employed workers; rents are monthly. All values CPI-adjusted to 2010 dollars. Pct HOLC D calculated on tracts with redlining maps. Distance from highway uses 1960 locations and constructed Interstates. Percent auto is share of workers using private vehicles. Counts and values are rounded following Census disclosure rules.

This segregation may have been shaped by various obstacles that discriminated against minority families. Although some policies ended before the 1960s, others persisted.¹⁰ During the decade of

¹⁰In the 1968 Kerner Commission Report to President Lyndon B. Johnson, commission members write “What white Americans have never fully understood — but what the Negro can never forget — is that white society is deeply implicated in the ghetto. White institutions created it, white institutions maintain it, and white society condones it.” Policies such as racial zoning established White-only districts through local ordinances, and restrictive covenants placed language in property deeds to prevent the sale of homes to anyone outside of the Caucasian race. Racial zoning was outlawed in the Supreme Court case *Buchanan v. Warley* in 1917. Restrictive covenants were ruled unenforceable in *Shelley v. Kraemer* in 1948, yet they continued to be found in property deeds until the 1950s (Corey et al. (2025)).

this study, segregation reached its peak after an extended period of Black migration from the rural South into neighborhoods in Northern cities ([Cutler et al., 1999](#); [Boustan, 2010](#)). It began declining after the 1968 Civil Rights Act—also known as the Fair Housing Act—but uneven enforcement meant reductions were gradual over time.

Figure 1: Suburbanization and Neighborhood Institutions



(a) Racial Covenants & Redlining in Minneapolis-St. Paul

(b) Suburbanization by Race

Notes: Kernel density plots of population use tract-level aggregates from IPUMS-National Historical Geographic Information System (NHGIS). Racial covenants were collected by researchers at the University of Minnesota ([Corey et al., 2025](#)). Redlining maps come from the American Panorama Project ([Nelson et al., 2020](#)).

Discrimination occurred through various formal and informal institutions that constrained residential choice ([North, 1991](#)). Figure 1a presents the Minneapolis metro area as an example where restrictive racial covenants in property deeds prevented sales to non-White households ([Jones-Correa, 2000](#)). These covenants were present mostly in suburban neighborhoods, which Figure 1b shows is where White families migrated out towards from 1950 to 1970. Conversely, Black households remained in the center, which were marked “redlined” in maps by the Home Owners’ Loan Corporation (HOLC), a federal agency formed in 1933 after the Great Depression to identify high-risk neighborhoods for mortgage financing.¹¹ Some researchers such as [Faber \(2020\)](#) and [Aaronson et al. \(2021\)](#) argue the HOLC maps directly increased segregation, but other scholars such as [Fishback et al. \(2020, 2022\)](#) demonstrate the maps reflected existing racial and economic characteristics and that HOLC did not itself discriminate in mortgage provision.

¹¹Concurrently, the Federal Housing Administration (FHA) also engaged in redlining by denying mortgage insurance to Black families, majority-Black neighborhoods, and socially or racially mixed areas ([Hillier, 2003](#)). While the HOLC maps are not the same as those by the FHA, some evidence suggests a correlation exists between the maps for Chicago ([Aaronson et al., 2021](#)). FHA maps for most cities have unfortunately been lost. [Fishback et al. \(2022\)](#) finds additional maps for Baltimore City, Maryland; Peoria, Illinois; and Greensboro, North Carolina.

This paper does not assume that segregation associated with the maps was necessarily caused by HOLC policies. For this study’s purposes, the HOLC maps proxy geographic borders where discrimination occurred, including from private actions such as racial covenants or refusal by landlords to rent to Black families outside of redlined neighborhoods. In later sections, using the microdata and estimated parameters, I decompose how much of the sorting by these maps is likely due to discrimination and how much is also attributable to economic differences, commuting patterns to workplaces, and social preferences of homophily (which can reinforce segregation at the borders). I provide evidence that discrimination is an important factor in the spatial distribution of households, which then interacts with highway infrastructure to have unequal impacts.

3 Empirical Evidence on Interstate Impacts

In this section, I develop an empirical strategy for causal identification and illustrate how Interstate highways impacted cities through their localized costs, commuting benefits, and subsequent equilibrium responses in neighborhood characteristics. These results motivate the key mechanisms of the quantitative model and the sources of quasi-experimental variation for parameter estimation.

3.1 Identification Strategy

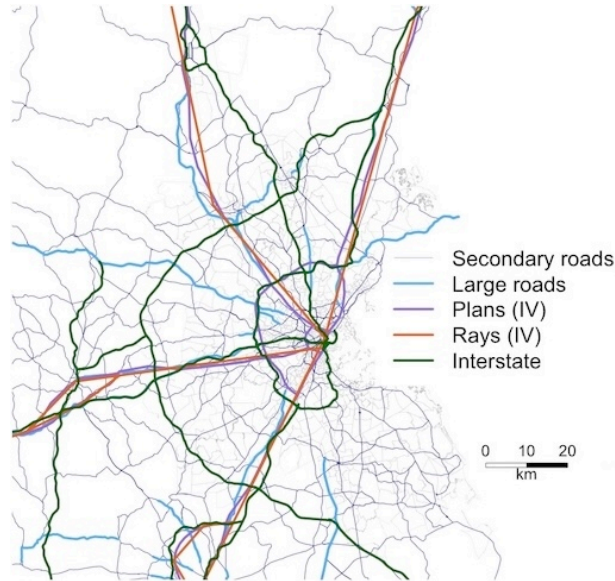
Non-random placement of Interstate routes can lead changes by highways to be contaminated by selection on trends. To obtain cleaner identification, I create comparison areas likely to have received an Interstate highway.

The 1944 report, *Interregional Highways*, recommended engineers: (1) build along existing roads with heavy traffic since a primary goal was to combat congestion, and (2) account for topographic features and other infrastructure.¹² Related to (1), I consider super-roads from the digitized Shell Atlases as Interstate candidates, where those not converted to highways are counterfactual control routes to be compared against. This strategy addresses [Borusyak and Hull \(2023\)](#)’s concern that transportation infrastructure tends to non-randomly impact areas depending on its location relative to existing markets, which can be alleviated if counterfactual networks are specified. In [Figure 2](#), I overlay the Interstate system on the historical network for the Boston area and illustrate that the two are closely aligned. Several historical roads were never re-built as Interstate highways, and these serve as the control routes. Related to (2), maps on railroads, canals, steam-boat navigable rivers for the late 19th century, bodies of water, shores, and ports are included as geographic controls since they influenced highway placement ([Atack, 2015, 2016, 2017](#); [Lee and Lin, 2017](#)).

While previous research has employed historical routes as instruments, past infrastructure influ-

¹²The introduction to *Interregional Highways* recommends that the “system follows in general the routes of existing Federal-aid highways” and Interstate development would occur through “the improvement of a limited mileage of the most heavily traveled highways.” The section Principles of Route Selection in Cities in *Interregional Highways* states there should be “desirable coordination of highway transportation with rail, water, and air transportation.”

Figure 2: Historical Road Networks and Highway Routes for the Boston Metro Area



Notes: Historical urban roads are split into two categories: secondary roads and large roads (superhighways in the legend of Shell Atlases), where large roads are candidates for Interstates. Planned routes are digitized from Yellow Book maps. Euclidean rays connect cities in the plans.

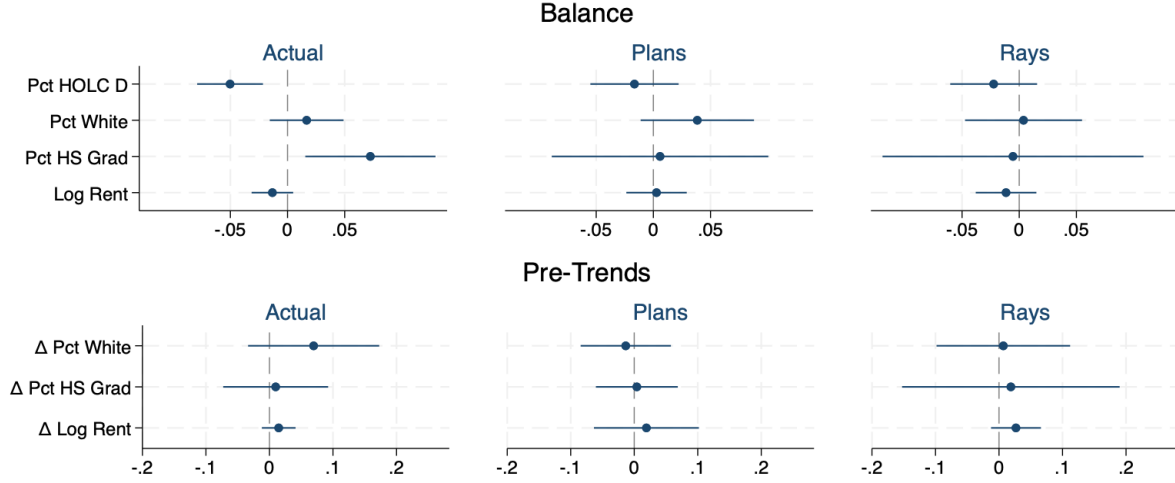
ences subsequent economic development and risks violating the exclusion restriction (Donaldson and Hornbeck, 2016). This paper instead purges these historical influences by including them as controls and consequently compares areas with similarly high levels of economic activity/traffic to areas that ultimately received Interstates.

Conditional on geographic features, the final placement of highway routes may continue to be biased due to local political factors, e.g. protests in high-income areas. To address this bias, transportation plans can be used as instruments since they were decided on before external influences occurred and because engineers were often indifferent to local socioeconomic conditions (Rose and Mohl, 2012). I digitize plans created by state engineers for 100 metro areas in the 1955 *General Location of National System of Interstate Highways* (informally called the “Yellow Book”) (Brinkman and Lin, 2022). These maps are consolidated with a 1947 plan from Baum-Snow (2007). I re-digitized at finer spatial scales to create a regional and metropolitan planned network.

Still, transportation planners may not have been fully neutral in their route choices. In a second strategy, I construct an Euclidean ray network that connects cities in the planned maps with straight lines, similar to the “inconsequential units” approach where neighborhoods coincidentally between cities are treated by Interstate highways (Chandra and Thompson, 2000; Faber, 2014; Morten and Oliveira, 2018). The Euclidean ray network is thus likely to be more quasi-random than the plans.

Figure 2 plots the two instruments next to the Interstate network for the Boston metro area and shows they are often adjacent.

Figure 3: Pre-Period Correlation & Pre-Trends for Highways and Instruments
Coefficient on Distance from Route



Notes: Data is 1940, 1950 and 1960 tract-level aggregates (IPUMS NHGIS). Tracts are limited to those within 5 miles of the nearest constructed route. The pre-trends cover either 1940 to 1950 or 1950 to 1960, depending on when highway construction started in the CBSA. Fixed effects are at the CBSA level. Standard errors are clustered by county. The geographic controls are log distance from the central business district, rivers, lakes, shores, ports, historical railroads, canals, and historical large roads. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

I measure the correlation at baseline and in pre-trends between distance from the various routes and neighborhood characteristics in a multivariate regression. Figure 3 shows the constructed highways were built further from more-educated areas and closer to redlined ones that were becoming lower income over time. Both instruments are not significantly correlated with tract features at baseline or in trends, although estimates for some variables are similar in direction to the Interstate ones (with larger standard errors). Note that identification relies only on pre-trends being satisfied since estimation is based on the time variation. Later, I present results using both instruments to provide a range of what the magnitudes could be. The first-stage regressions, shown in Supp. Appendix C.1, indicate that F-statistics are all above 100.

3.2 Population and Equilibrium Responses By Highways

Using this identification strategy, I first present some stylized facts on the effects by highways as indicative of their costs. The long differences specification estimates changes in population at the tract-level, denoted by i , which revealed preference logic implies is correlated with the impacts of highways, and equilibrium changes in neighborhood rents, educational, and racial composition.

$$\Delta \log Y_i = \beta_1 \log DistHW_i + \beta_2 \log DistCBD_i + \beta_3 Redlined_i + \mathbf{X}_i \eta + \gamma_{m(i)} + \epsilon_i \quad (1)$$

Differences are over 1960 to 1970 (and occasionally 1950 to 1960 for cities with earlier construction, stacked together) using the expanded set of cities in the public-use dataset.¹³ The coefficient on distance from highways $DistHW_i$ represents the costs. Distance from the central business district $DistCBD_i$ is used as a control to absorb commuting access benefits correlated with suburbanization. A redlined indicator captures heterogeneity in redlined versus non-redlined areas, so the empirical variation comes from within the two types of neighborhoods. CBSA fixed effects $\gamma_{m(i)}$ for each city m are included to exploit only within-metro area variation. Standard errors adjust for spatial correlation following Conley (1999) within a radius of 1 kilometer.

Results are presented in Figure 4, which shows significant declines by highways in population and rents, and that neighborhoods become less White.¹⁴ The changes in racial makeup are driven by White households leaving, as there is no statistically measurable response by Black households. Interestingly, there is very little effect on educational composition, only racial composition. Home values also do not adjust significantly, as shown in Supp. Appendix Table A.1.

Comparing magnitudes of outcomes, the changes in rents and racial composition are smaller than the White population response, so for welfare impacts, the large reallocation of White households may be more meaningful for their gains than adjustments in these two characteristics.

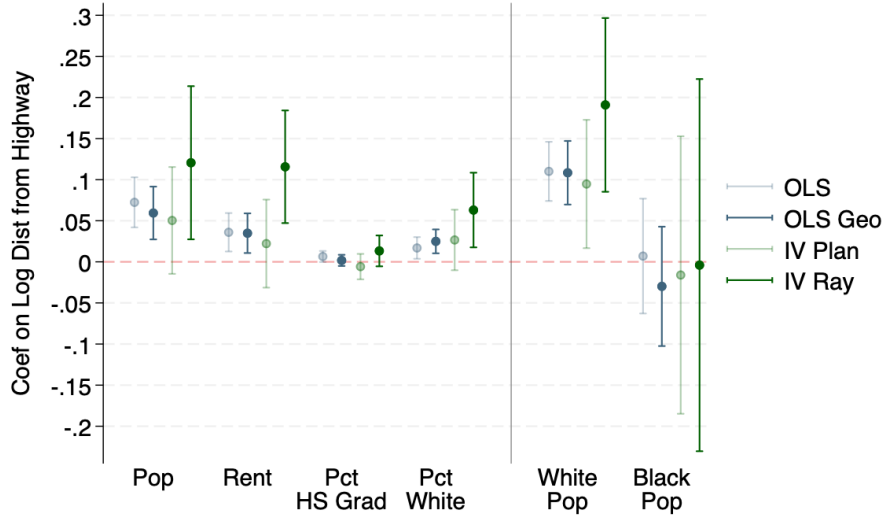
These results are consistent across all the specifications. Including geographic controls does not substantially alter the effect sizes, so selection is minimal once $DistCBD_i$ is controlled for. Instrumenting with the plans also does not affect the size of the estimates greatly, although instrumenting with the rays tends to raise the standard errors and the point estimate.

Feedback channels link the neighborhood characteristics. As income is correlated with race, a positive relationship between changing rents and racial composition may be due to differential responsiveness to price changes i.e. non-homotheticity in consumption. Preferences for racial composition further reinforce sorting. For example, when an area becomes less White after a direct shock, the feedback effect of homophilic preferences leads to more out-migration of White households. Migration then transmits into housing prices. The equilibrium system should thus aim to characterize how the channels are determined simultaneously and measure the importance of each.

¹³Tracts in cities where less than 10% of the mileage of Interstate highways was built in 1960 are in the 1960 to 1970 sample. Tracts in cities where less than 10% of the mileage of Interstate highways was built in 1950 (occasionally some cities began construction on Interstate highways before the Federal Highway Act of 1956) but more than 10% was built by 1960 are in the 1950 to 1960 sample. Cities here are Core Based Statistical Areas and include both Metropolitan Statistical Areas and Micropolitan Statistical Areas.

¹⁴In Supp. Appendix Figures B.1 and B.2, I present results in non-parametric bins over distance from highways in panels grouped by distance from the CBD. These figures depict the curvature of the decline near roads, and given that OLS is comparable to IV, they can also be interpreted as representing the costs of highways.

Figure 4: Changes Over Distance from Highway (1950-1960, 1960-1970)



Notes: Observations are census tracts (5 mi from nearest highway; ≤ 30 mi from CBD), differenced over 1950–60 or 1960–70 depending on highway construction timing in the CBSA (IPUMS NHGIS). CBSA fixed effects included; Conley SEs (1 km) are reported. All specifications include Dist CBD and the gradient (Dist CBD/Dist Highway) as controls. Specifications OLS Geo, IV Plan, IV Ray also control for log distance from rivers, lakes, shores, ports, historical railroads, canals, and historical large roads. Redlined tracts are those with $> 80\%$ area redlined. Kleibergen-Paap rk Wald F statistics are 613.2, 466.7 for the plan and ray instruments, respectively.

3.3 Population Elasticities to Commuter Market Access

Next, I measure population responses to the commuting benefits of highways, which contribute to suburbanization during this period. Similarly to the results for migration away from highway costs, I examine whether race versus education is more important and the differences between White vs. Black households for residential reallocation towards highway benefits.

To pinpoint highway impacts separately from ongoing migration away from city centers, I exploit the growth in Commuter Market Access (CMA) from the reduction in travel time from Interstate construction. These connectivity improvements are compared against existing connections from the historical roads while controlling for $DistCBD_i$. The variation is then between suburbs connected by Interstates to other suburbs not connected.

Residential CMA is defined for each tract i and aggregates over workplaces denoted with j :

$$CMA_{igr} = \left(\sum_j \omega_{jgr} / d_{ijgr}^\phi \right)^{\frac{1}{\phi}}$$

CMA is always heterogeneous by education $g \in \{L, H\}$, for less-educated and high-educated, and race $r \in \{B, W\}$, for Black and White. Using the richness of the microdata, I measure how workplaces pay group-specific wages ω_{jgr} (scaled by employment) and calculate the commute costs d_{ijgr} as a weighted average of commute times by car and *other modes of transit* with weights that

differ by group and ij pair. The change in CMA from Interstate development then accounts for the pre-existing presence of public transit and the location of high-wage jobs, which differentially affects each race \times education group. Parameter ϕ is a substitution elasticity over workplaces and is set to 3 in the middle of estimates from the literature for the stylized facts (Ahlfeldt et al., 2015; Morten and Oliveira, 2018; Severen, 2021).

In the Decennial microdata, I measure the elasticity of how population L_{igr} responds to improvements in CMA from 1960 to 1970.

$$\Delta \log L_{igr} = \beta_r \Delta \log CMA_{igr} + \mathbf{X}_i \mu_r + \psi_{m(i)} + v_{igr}$$

The controls X_i include $DistCBD_i$ to exploit variation in concentric rings around cities, i.e. within the suburbs, as well as other geographic controls of railroads, canals, etc., and CBSA fixed effects.

The empirical variation is also relative to the comparison roads as following Borusyak and Hull (2023), I take a control function approach and construct CMA where the possible counterfactual shocks of large historical roads are converted into Interstate highways (displayed in Supp. Appendix Figure B.3). Borusyak and Hull (2023) argues this re-centering addresses non-exogenous exposure where areas connected by highways are systematically different in the existing network.

Results are reported in Table 2 with standard errors clustered at the tract level and Conley (1999) standard errors in brackets. The population elasticity is around 1.4 for the White population across Columns 1–2 where Column 2 includes counterfactual CMA with historical large roads built as highways. Because the estimates do not vary greatly, non-exogenous exposure to the highway shock does not drive the findings. Elasticities for the Black population are much lower than for White households at 0.1 and are insignificant. Consistent with the previous results on the lack of movement away from highway costs, Black households do not respond to the benefits of highways.

This differential migration is not explained by the education differences across racial groups. Column 3 shows that less-educated White households are just as responsive to CMA improvements as their higher-educated counterparts, yet Black households remain far less mobile at both education levels. This pattern also indicates that economic status is not a key driver of racial differences in migration since Table 1 demonstrates that higher-educated Black households earn wages and pay home prices similar to less-educated White ones. In a similar vein, declining rents in city centers over time cannot explain the gap since controlling for changes in prices leaves the Black population elasticity to CMA virtually unchanged (see Supp. Appendix C.2).

The previous descriptive evidence in Section 2 suggested that barriers to choice could be important for the low mobility response of the Black population. I explore how this shapes the population elasticities in Column 4, which includes redlining by race fixed effects. The specification then uses variation within types of neighborhoods, i.e. within redlined neighborhoods that are already racial integrated and less likely to exhibit housing discrimination.

Population elasticities for White households are reduced in size to around 1, so some of their earlier estimated response to CMA improvements was across types e.g. by moving from redlined to non-redlined neighborhoods in the suburbs. For Black households, elasticities are now around 0.3 and statistically significant, though still lower than for White households. Their dampened overall elasticities mask how Black households respond to CMA changes in redlined areas and how spatial frictions inhibit the Black population from leaving centrally located, redlined neighborhoods for suburban, non-redlined one. Lastly, to show that racial homophily is not leading Black households to stay in the center, which is becoming more diverse over time, Supp. Appendix C.2 includes a result that controls for changing racial composition, and again, the estimate remains the same. In the model simulations, I will further decompose the sources of segregation after directly estimating the homophily parameter.

Table 2: Elasticity of Population to Commuter Access

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	OLS	$\Delta \log L_{igr}$ (Δ Log Population 1960–1970) + BH (2023)	Race \times Educ	+ Redlining FE	Plans IV	Rays IV
$\Delta \log CMA_{igr}$						
Black	0.0907 (0.0968) [0.110]	0.0941 (0.0968) [0.110]		0.273*** (0.100) [0.116]	−1.757 (1.276) [1.490]	−3.062* (1.564) [1.838]
White	1.401*** (0.115) [0.143]	1.410*** (0.115) [0.143]		1.083*** (0.125) [0.157]	0.648** (0.323) [0.456]	0.719** (0.340) [0.458]
Black <HS			0.218* (0.124)			
Black HS Grad			−0.712*** (0.155)			
White <HS			0.958*** (0.127)			
White HS Grad			0.946*** (0.141)			
R-squared	0.113	0.113	0.139	0.118	0.099	0.072
CBSA FE	Yes	Yes	Yes	Yes	Yes	Yes
Geo Controls	Yes	Yes	Yes	Yes	Yes	Yes
Rounded Obs	N = 60 500					

Notes: Observations are census tracts by race and education in first differences from 1960–70. Data is restricted Census microdata. Tract-clustered SEs are reported with Conley SEs (1 km) in brackets. Included are CBSA fixed effects and controls: log distances to CBD, river, lakes, shorts, ports, railroads, canals, historical roads, all interacted with race (and education for Col 3). The [Borusyak and Hull \(2023\)](#) control for CMA in large roads is interacted with race in Col 2 (and education in Col 3). Redlining fixed effects are interacted with race. Col 5-6 include the [Borusyak and Hull \(2023\)](#) control interacted with race and CBSA fixed effects. Kleibergen-Paap rk Wald and Cragg-Donald Wald F statistics for Col 5-6 are 35, 25 and 203, 139. Counts rounded to the nearest 500 to meet Census disclosure rules. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

In the endogenous variable of $\Delta \log CMA_{igr}$, wages and employment in ω_{igr} , not only commute costs, adjust from 1960 to 1970. Employing only commuting variation from the highway shock, I

define the instrument $\Delta \log CMA_{igr}^{IV} = \frac{1}{\phi} (\log \sum_j \omega_{jgr,1960} / d_{ijgr}^{IV\phi}) - \frac{1}{\phi} (\log \sum_j \omega_{jgr,1960} / d_{ijgr,1960}^\phi)$ where I fix scaled wages to 1960 levels and only adjust the commute costs in d_{ijgr}^{IV} using the change in commute times from the plans or the Euclidean rays.¹⁵

I report IV estimates in Columns 5-6.¹⁶ Coefficients are smaller than with OLS, so the previous estimates may include responses to endogenous wage and employment changes rather than solely the Interstate shock or selection of highway routes in growing places. Black population responses are imprecisely estimated as standard errors are large. Yet overall, the estimated coefficients indicate strong treatment effects on migration.

3.4 Discussion

Building on these empirical facts, in the next section, I lay out a quantitative urban model that expands the analysis in several ways. To start, while the reduced form evidence is informative for some of the impacts, it combines both direct and indirect effects (such as endogenous reallocation and adjustments in equilibrium outcomes) which simultaneously shape welfare. The model is rich enough to encompass all channels and carefully consider the forces at play for welfare.

Additionally, the empirical estimates recover treatment effects (i.e. coefficients), but they are silent on *incidence*, which depends on the extent of exposure by groups to the treatment and is central to distributional measurement. The model framework provides a structure to allocate benefits, costs, and equilibrium changes across groups.

Finally, how discrimination shapes highway effects has been examined incompletely since the empirical sample includes only areas where Black households resided, leaving out those where they are never observed because of neighborhood discrimination. The model enables asking counterfactual questions, such as how opening up neighborhood access changes sorting by race and inequality in Interstate impacts.

4 A Quantitative Model of Cities

In the sections below, I describe the key pieces of the spatial equilibrium framework to measure the impacts of the Interstate highway system, which is quantified for the 25 metro areas in the Census microdata. Extending previous advances by [Allen and Arkolakis \(2014\)](#), [Ahlfeldt et al. \(2015\)](#), and [Tsivanidis \(2023\)](#), the general equilibrium model maps the sources of segregation to components of classic urban models and incorporates residential barriers that ultimately influence

¹⁵Since commute times are all computer generated, the change in commute costs comes from the addition of the segments of the Interstate highway system built between 1960 and 1970 as well as changes in mode of transport weights by race and education between 1960 and 1970 (all groups increase their car usage). The functional form for d_{ijgr} is detailed in the model section. $\omega_{jgr} = T_{jgr}(w_{jgr})^\phi$ is scaled wages, also explained in the model section.

¹⁶I find the Kleibergen-Paap rk Wald and Cragg-Donald Wald F-statistics are all far above 10. Additional details on how the instruments are defined and the first-stage regressions are in Supp. Appendix C.3.

welfare inequality. Neighborhoods are linked via commuting networks, and transportation infrastructure lowers the costs of travel, which in turn affects the rest of the spatial economy.

4.1 Model Features

Workers are differentiated by education $g \in \{L, H\}$ for less-educated and higher-educated groups and by race $r \in \{W, B\}$ for White and Black groups. Each metro area consists of neighborhoods indexed by $i = 1, \dots, S$ and contains fixed population levels \mathbb{L}_{gr} by education and race. I focus on a closed city set-up to emphasize the *within-city* impacts of highways since the literature has previously examined regional impacts and in the empirical estimation, CBSA fixed effects absorb any city-level migration.

Workers – Individuals (o) choose where to live (i) and work (j) depending on idiosyncratic shocks and location characteristics to maximize the utility function:

$$\begin{aligned} \max_{c_{ij}(o), l_i(o)} \quad & \frac{z_i(o) \varepsilon_j(o) (1 - \tau_{igr}^b) B_{igr}}{d_{ijgr}} \left(\frac{c_{ij}(o)}{\beta_{gr}} \right)^{\beta_{gr}} \left(\frac{l_i(o)}{1 - \beta_{gr}} \right)^{1 - \beta_{gr}} \\ \text{s.t.} \quad & c_{ij}(o) + (1 + \tau_{igr}^Q) Q_i l_i(o) = w_{jgr} \varphi_{gr} \end{aligned}$$

Preferences are Cobb-Douglas over consumption $c_{ij}(o)$ and residential floorspace $l_i(o)$. Amenities B_{igr} are group-specific and contribute to heterogeneous choices. Differential sensitivity to housing prices Q_i appears through non-homothetic preferences where the β_{gr} share of consumption varies by education and race, a tractable approach in the literature to study sorting (Davis and Ortalo-Magné, 2011; Balboni et al., 2020; Diamond and Gaubert, 2021).¹⁷ Wage w_{jgr} at workplaces j are set by firms in equilibrium, and traveling from i to j entails commute costs d_{ijgr} that reduce utility with the functional form $d_{ijgr} = (t_{ijgr})^{\kappa_{gr}}$ adopted from Heblich et al. (2020). Parameter κ_{gr} translates times t_{ijgr} into costs, which depend on public transit/other transport usage by each group.

Incorporating homeownership in φ_{gr} , the budget constraint includes income from redistributed rents based on the ratio of home values owned by each group, akin to holding a portfolio of homes, such that total income for each group equals the sum of labor and rental income.

$$\begin{aligned} \underbrace{\varphi_{gr} \sum_i \bar{w}_{igr} L_{igr}}_{\text{total income}} &= \underbrace{\sum_i \bar{w}_{igr} L_{igr}}_{\text{total labor income}} + \underbrace{\sum_i \hat{o}_{igr} \sum_{g,r} (1 - \beta_{gr}) \bar{w}_{igr} \varphi_{gr} L_{igr}}_{\text{total rental income}} \\ \Rightarrow \varphi_{gr} &= 1 + \frac{\sum_i \hat{o}_{igr} \sum_{g,r} (1 - \beta_{gr}) \bar{w}_{igr} \varphi_{gr} L_{igr}}{\sum_i \bar{w}_{igr} L_{igr}} \quad \text{where} \quad \bar{w}_{igr} = \sum_j \pi_{j|igr} w_{jgr} \end{aligned}$$

The share of home values \hat{o}_{igr} is observed in the data as the fraction of the value of homes owned

¹⁷Cobb-Douglas with varying shares β_{gr} allows for price changes to generate sorting but does not accommodate income changes leading to sorting compared to Stone-Geary. In Supp. Appendix D.1.1, I provide an extension with Stone-Geary preferences.

by group gr out of the value of all homes in a neighborhood.

Spatial barriers can arise in a couple forms. A group-specific amenity wedge $\tau_{igr}^b \geq 0$ affects whether individuals desire to live in a location, e.g. due to discrimination. A group-specific price wedge $\tau_{igr}^Q \geq 0$ leads groups to experience different effective housing prices even when the nominal price is the same, e.g. through barriers in credit access.¹⁸

Beyond group-level factors, workers additionally have idiosyncratic preferences for residences $z_i(o)$ drawn from a Frechet distribution $F(z_i(o)) = \exp(-z_i(o)^{-\theta_r})$ and for workplaces $\varepsilon_j(o)$ from $F(\varepsilon_j(o)) = \exp(-T_{jgr}\varepsilon_j(o)^{-\phi})$ where T_{jgr} is a scale parameter representing the size of the workplace and amenities beyond wages. θ_r is a shape parameter for the dispersion of shocks and responsiveness to changes in the attractiveness of residences, i.e. a substitution elasticity for mobility across neighborhoods. Following the evidence that Black and White households respond differently to CMA improvements, θ_r is heterogeneous by race. Likewise, ϕ is a workplace elasticity governing the responsiveness of choices to workplace changes.¹⁹

After utility maximization, indirect utility is expressed as:

$$u_{ijgr}(o) = \frac{z_i(o)\varepsilon_j(o)(1 - \tau_{igr}^b)B_{igr} \left((1 + \tau_{igr}^Q)Q_i \right)^{\beta_{gr}-1} w_{jgr}\varphi_{gr}}{d_{ijgr}}$$

With this indirect utility expression, population levels at locations are derived using the Frechet properties of $\varepsilon_j(o)$. Conditional on living in i , the probability a worker works in j is

$$\pi_{j|igr} = \frac{T_{jgr}(w_{jgr}/d_{ijgr})^\phi}{\sum_s T_{sgr}(w_{sgr}/d_{isgr})^\phi} = \frac{T_{jgr}(w_{jgr}/d_{ijgr})^\phi}{\Phi_{igr}} \quad (2)$$

With commute costs scaled by elasticity ϕ , the commuting elasticity v_{gr} combines the workplace elasticity ϕ with the commute cost parameter κ_{gr} such that $(d_{ijgr})^\phi = (t_{ijgr})^{\kappa_{gr}\phi} = (t_{ijgr})^{v_{gr}}$. The denominator Φ_{igr} is a transformation of the commuter market access (CMA) measure introduced before following $CMA_{igr} = \Phi_{igr}^{1/\phi}$. Labor supply L_{Fjgr} aggregates over all residences and the probability each residence sends workers to j

$$L_{Fjgr} = \sum_i \pi_{j|igr} L_{igr} \quad (3)$$

where L_{igr} is the population of group gr workers at residence i .²⁰ The probability a worker lives in i is of a similar form using the Frechet properties of the residential shocks, and combined with the

¹⁸In Supp. Appendix D.1.2, I include an extension with a Nested structure such that mobility is differential across types of neighborhoods. For a more parsimonious framework, this feature is not included in the main model.

¹⁹Departing from the canonical Ahlfeldt et al. (2015) model, I allow for separate residence and workplace shocks as the earlier reduced form residential elasticities are much smaller in magnitude compared to estimates of ϕ found in the literature (Monte et al., 2018; Severen, 2021). See Supp. Appendix D.2 for an expanded discussion of this choice.

²⁰Expected income at location i can be computed by weighting wages with the probability of commuting to workplace j . $\bar{w}_{igr} = E[w_{jgr}|i] = \sum_j \pi_{j|igr} w_{jgr} = \sum_j \frac{T_{jgr}(w_{jgr}/d_{ijgr})^\phi}{\sum_s T_{sgr}(w_{sgr}/d_{isgr})^\phi} w_{jgr}$.

total city population of a group \mathbb{L}_{gr} , we arrive at the key equation for residential sorting:

$$\pi_{igr} = \frac{\left((1 - \tau_{igr}^b)B_{igr}CMA_{igr} \left((1 + \tau_{igr}^Q)Q_i\right)^{\beta_{gr}-1}\right)^{\theta_r}}{\sum_t \left((1 - \tau_{igr}^b)B_{tgr}CMA_{tgr} \left((1 + \tau_{igr}^Q)Q_t\right)^{\beta_{gr}-1}\right)^{\theta_r}} \quad (4)$$

$$\Rightarrow L_{igr} = \pi_{igr}\mathbb{L}_{gr} \quad (5)$$

Sources of Segregation – With the factors characterizing residential choice, sorting by race and education arises from (1) group-specific commuter market access, including differential firm location and mode of transport usage, (2) differing substitution elasticities, (3) housing prices which, while not group-specific, are valued differentially by race and education,²¹ (4) group-specific amenities, and (5) spatial barriers as residual wedges. I expand on a couple components below.

Racial preferences such as homophily appear in amenities through the component that is endogenous in racial composition L_{iW}/L_i .

$$B_{igr} = b_{igr} \underbrace{(L_{iW}/L_i)^{\rho_r}}_{\text{Pct White}} \quad (6)$$

Preference parameter ρ_r can capture how retail amenities or public goods like school quality are correlated with racial composition, or taste-based factors such as prejudice or cultural similarity (Becker, 1971; Diamond, 2016; Almagro and Dominguez-Iino, 2020). The remaining fundamental component b_{igr} is for time-invariant factors such as persistent natural geography.

Spatial barriers appear in the model as wedges that are invariant to highway policy.²² In estimation, they will be mapped to residual differences in location that remain after accounting for the other factors in the choice expression. Some of sorting can be related to differences directly observed in the data, such as in sensitivity to home prices and CMA (encompassing firm location, wages, and public transit use). In addition, racial homophily must be measured credibly before estimating the wedge since stronger homophily would lower how much is attributed to barriers.

Within the set of barriers, further disambiguating them is challenging since they are often correlated with each other. Resistance to racial integration by property owners may produce preference (amenity) wedges around the same neighborhood borders that divided rental units from single-family developments, where price wedges also arise through the limited access to low-interest

²¹Balboni et al. (2020) have a segmented housing construction sector where prices are group-specific. In this setting, prices are not sufficiently different by race after accounting for quality controls and neighborhood fixed effects to merit segmented housing. See Supp. Appendix Table E.13.

²²Institutions may be a function of the proportion of the neighborhood that is White i.e. through endogenous institutions, but other institutions are codified into law and persistently invariant to the racial composition of the neighborhood. Aaronson et al. (2021) find a border discontinuity in racial composition at redlining borders even as non-redlined areas became more racially diverse over time. Zoning is an endogenous exclusionary barrier that arises as neighborhood racial composition changes, as studied in Lee (2022), Song (2022), and Krimmel (2022).

mortgages from the Federal Housing Administration (Rothstein, 2017). However, data on credit access is scarce for this time, so price wedges are difficult to measure. Direct discrimination in prices seems minimal, since I find Black and White households pay essentially the same to live in any particular area (see Supp. Appendix E.2.1).²³

In Supp. Appendix D.3, I show how all barriers can be mapped to a single wedge, given the isomorphisms between the amenity and price wedges. They are also equivalent to a capacity constraint that fixes the number of households from the minority group. Intuitively, given the Cobb-Douglas form of utility, higher amenities translate into lower prices, which provides a mapping from amenity wedges to price wedges (however, price wedges have different implications for welfare since they also affect the housing market). To attain the same allocation as the capacity constraint, either of the two wedges must sufficiently increase to reduce residential population. In conclusion, I include a single residential barrier that is essentially the amenity wedge.

Firms and Housing – As worker mobility across locations reacts to reductions in commute costs, firms alter wages in equilibrium and housing supply responds to affect prices. These adjustments are not as central to the paper as residential choices, so I relegate these features to Supp. Appendix D.4. They are necessary to close the model and conduct a comprehensive assessment. In the counterfactual exercises, I probe their importance for welfare.

To summarize, firms are perfectly competitive using Cobb-Douglas technology over labor and housing. Labor is a Nested CES aggregate over education and race types, and productivity by group differs across locations. Agglomeration in density alters firm productivity. The housing construction sector responds to changes in demand following a constant elasticity structure with an arbitrage condition over residential versus commercial uses.

Welfare – Finally, welfare up to a normalization constant, U_{gr} , aggregates over all residential locations accounting for amenities, commuter access, prices, and homeownership.

$$U_{gr} = \left(\sum_i \left((1 - \tau_{igr}^b) B_{igr} \underbrace{\left(\sum_j T_{jgr} (w_{jgr}/d_{ijgr})^\phi \right)^{\frac{1}{\phi}}}_{CMA_{igr}} Q_i^{\beta_{gr}-1} \phi_{gr} \right)^{\theta_r} \right)^{1/\theta_r} \quad (7)$$

²³While the qualitative literature has cases of discriminatory pricing preventing Black households from living in White neighborhoods as in Taylor (2019), I do not find Black families faced substantially higher prices for similar quality housing. In Supp. Appendix E.2.1, after including neighborhood fixed effects and house quality controls, Black households face 3% higher rents in non-redlined areas and 8% higher rents in redlined areas. As the differential is not greater in non-redlined areas, the concentration of Black households there can not be explained by lower price discrimination in redlined areas. However, the positive race differential suggests some discrimination.

4.2 Impacts of the Interstate Highway System

Commuting benefits of highways lead to declines in bilateral times t_{ijgr} in the commute cost function $d_{ijgr} = t_{ijgr}^{\kappa_{gr}}$. These reductions improve commuter access differentially across locations depending on which bilateral pairs are connected and wages at workplaces.

Localized costs of highways scale fundamental amenities b_{igr} and decay over distance $DistHW_i$ at the rate η (Brinkman and Lin, 2022). At $DistHW_i = 0$, fundamental amenities are discounted by $1 - b^{HW}$, and remaining amenities are contained in \bar{b}_{igr} .

$$b_{igr} = \bar{b}_{igr}(1 - b^{HW} \exp(-\eta DistHW_i)) \quad (8)$$

Residential Choice Expression – In summary, the Interstate system generates changes in *fundamentals* of commute times between places and amenities by highways which through the general equilibrium system of equations lead to adjustments in the *equilibrium objects* of endogenous amenities, housing prices, and wages. Residential choice, expanded below, evolves with direct highway impacts and with equilibrium adjustments across residences and workplaces.

$$L_{igr} = \left(\underbrace{\bar{b}_{igr}(1 - \tau_{igr}^b)}_{\text{Institutions}} \underbrace{(1 - b^{HW} \exp(-\eta DistHW_i))}_{\text{Local Costs}} \underbrace{(L_{iW}/L_i)^{\rho_r}}_{\text{Pct White}} \right) \times \left(\sum_j T_{jgr} \underbrace{(w_{jgr})^\phi}_{\text{Wages}} * \underbrace{(t_{ijgr})^{-\kappa_{gr}\phi}}_{\text{Commute Times}} \right)^{\frac{1}{\phi}} \times \underbrace{Q_i^{\beta_{gr}-1}}_{\text{Prices}} \mathbb{L}_{gr} U_{gr}^{-\theta_r} \quad (9)$$

Note that if much of the cross-sectional variation in where Black households live appears in time-invariant wedges, only large shocks can alter the degree of segregation. Although Interstate highways impacted cities immensely, they may not be sufficiently large to greatly affect Black residential locations, in line with the observed low Black migration in the stylized facts.

Impacts to Welfare in Equilibrium – Welfare changes are tightly tied to residential choices and can be expressed in exact-hat algebra form $\hat{x} = x'/x$ to show the dependence on initial allocations. The change in welfare $\hat{U}_{gr} = U'_{gr}/U_{gr}$ follows

$$\hat{U}_{gr} = \left(\sum_i \pi_{igr} \left(\underbrace{\hat{b}_{igr}}_{\text{Fund Amen}} \times \underbrace{(\hat{L}_{iW}/\hat{L}_i)^{\rho_r}}_{\text{Pct White}} \left(\sum_j \pi_{j|igr} \underbrace{(\hat{w}_{jgr})^\phi}_{\text{Wages}} \times \underbrace{(\hat{t}_{ijgr})^{-\kappa_{gr}\phi}}_{\text{Commute Times}} \right)^{\frac{1}{\phi}} \underbrace{\hat{Q}_i^{\beta_{gr}-1}}_{\text{Prices}} \underbrace{\hat{\phi}_{gr}}_{\text{Homeown}} \right)^{\theta_r} \right)^{1/\theta_r} \quad (10)$$

and is determined by the (1) initial distribution of groups across locations in π_{igr} and $\pi_{j|igr}$, (2) changes in *fundamentals* and in *equilibrium outcomes*, and (3) elasticities to residential and workplace shocks. If Black households have lower residential elasticities, i.e. $\theta_B < \theta_W$, their incidence

to the shocks is stronger. Furthermore, low elasticities imply that initial residential locations, which may be heavily determined by time-invariant wedges, are even more important for welfare impacts.

4.3 General Equilibrium and Uniqueness

Definition 1. Given the model’s parameters, city populations by education and race, and location characteristics, the general equilibrium is represented by a vector of endogenous objects including $\{L_{igr}, L_{Fjgr}, Q_i, w_{jgr}, B_{igr}, U_{gr}\}$ determined by the set of equations governing residential demand, labor supply, housing demand from residents and firms, housing supply, zero profit and profit maximization by firms, and the closed-city assumption. More details are in Supp. Appendix D.5.

The equilibrium defined has many sources of spillovers, most immediately via endogenous amenities and agglomeration externalities, and thus the possibility of non-uniqueness.

Proposition 1. *There exists a unique equilibrium when model parameters satisfy the condition $\rho(A) < 1$ where A is a matrix of elasticity bounds on the economic interactions across endogenous equilibrium outcomes and $\rho(A)$ is the spectral radius.*

Proof. See Supp. Appendix F.4 □

I follow Allen and Arkolakis (2022) where I rewrite the equilibrium conditions as a set of H types of interactions conducted by the set of N heterogeneous agents and then construct the $H \times H$ matrix of the uniform bounds of the elasticities. With these conditions on model parameters, I derive theory-consistent equations to estimate parameter values next.

5 Parameter Estimation and Model Inversion

The steps for estimation and inversion are intertwined, so I begin by summarizing the overarching goals. Throughout this summary, I briefly include results for parameters that are more standard to estimate in the literature. Later, I present the full estimating equation for the residential parameters since they are central to inferring how much of segregation comes from discrimination and the population responses to the Interstate highway system.

5.1 Estimation and Inversion Overview

Parameter Estimation – The focus of estimation is on two main groups of parameters: (1) direct impacts of Interstate highways through commuting connectivity and local harms near routes, and (2) the sources of segregation.

To measure commuting benefits, a key initial step is estimating the “gravity” equation for how commute flows relate to commute times by race and education. This equation is derived from the commute shares in Eq. (2) and the functional form of commute costs as $d_{ijgr} = t_{ijgr}^{\kappa_{gr}}$. Using

the planned and ray instruments and the Poisson-Pseudo Maximum Likelihood (PPML) estimator following [Silva and Tenreyro \(2006\)](#), I obtain commuting elasticities $v_{gr} = \kappa_{gr}\phi$ around 4 for all groups. Parameter v_{gr} combines the commute cost parameter κ_{gr} with the workplace substitution elasticity ϕ , and it enters into the CMA measures. The workplace elasticity is assigned from the literature to $\phi = 3$ following studies with settings similar to this paper.²⁴ Supp. Appendix [E.2.2](#) provides more details on gravity estimation.

Commuting elasticities on hand, I construct instruments to estimate some of the sources of segregation, residential elasticity θ_r and racial preferences ρ_r , by exploiting quasi-random variation from the highway shock. Building on the reduced form empirical equations, CMA improvements directly affect residential attractiveness, providing variation for θ_r . They indirectly alter racial composition as population responds in race-specific ways to CMA, providing variation for ρ_r .

Housing price sensitivity, i.e. the consumption share of housing $1 - \beta_{gr}$, is calibrated using the Consumer Expenditure Surveys (CEX) microdata in 1980. Supp. Appendix [E.2.3](#) describes how calibration occurs.

With the parameters θ_r , β_{gr} , and ρ_r , I invert the model to obtain fundamental amenities b_{igr} (including the wedge) as the residual component of population choices unexplained by characteristics such as prices, racial composition, or commuting access. This residual is then projected over distance from routes to measure local costs in non-parametric bins. I find that amenities drop by 19% in the first 0.5 mile by highways, and to assign parameter values for b^{HW} and η , I match the functional form of $b_{igr} = 1 - b^{HW} \exp(-\eta DistHW_i)$ to the estimated values. In Supp. Appendix [E.2.4](#), I additionally conduct a placebo check around historical large roads and show that local costs are correlated with modern-day pollution measures.

Lastly, in Section 7, I return to the residual component of residential choice b_{igr} to infer discriminatory barriers as a location-race-specific wedge. As a time-invariant term, however, it is not necessary for quantification of highway impacts and will only be used for *counterfactual* analysis.

Model Inversion – In tandem with parameter estimation described above, model inversion occurs in the background to acquire components that enter estimation. As described in greater detail in Supp. Appendix [E.1](#), inversion uses the set of parameters (partially estimated, partially from the literature) to map observed data on residential and workplace populations, commute times, housing prices, and wages to productivity and residential amenities. During this process, several location characteristics such as T_{jgr} are also inferred.

Using the commuting equation for labor supply in Eq. (3) and following the iterative procedure of [Allen and Arkolakis \(2014\)](#), I invert for workplace factors $\omega_{jgr} = T_{jgr}(w_{jgr})^\phi$ which combines

²⁴The elasticity ϕ has been estimated in various contexts and ranges from 6.8 in [Ahlfeldt et al. \(2015\)](#) during the division of Berlin, 1.9 in [Morten and Oliveira \(2018\)](#) with highway expansion in Brazil, 3.3 in [Monte et al. \(2018\)](#) with commuting data in the U.S, and 2.18 in [Severen \(2021\)](#) with development of the Los Angeles Metro Rail.

observed wages with the scale parameter T_{jgr} .²⁵ Aggregating the workplace factors into the CMA measure and combining CMA, rents, and the estimated parameters θ_r and β_{gr} , I infer amenities B_{igr} up to scale following the residential share expression in Eq. (4).

Not central to the paper but necessary for the equilibrium analysis, I calibrate parameters in the production function using the Nested CES structure for labor demand, wages by group, and elasticities of substitution by race and education. Productivity is determined by the zero profit condition. As the workplace data is at the POW Zone, I assume that the distribution of economic activity across tracts is uniform within the POW Zone. Housing supply, land used in housing production, and the allocation across residential and commercial uses are recovered from the conditions for residential and commercial demand. The additional parameters on the production function and housing supply construction sector are described in Supp. Appendix E.2.5.

5.2 Residential Elasticity and Preferences as Endogenous Amenities

I now estimate the residential elasticity θ_r and racial preferences ρ_r with the equation below which relates population flows to changes in CMA and racial composition, similar to the stylized facts.

$$\Delta \log L_{igr} = \theta_r \Delta \log CMA_{igr} + \underbrace{\tilde{\rho}_r}_{\theta_r \rho_r} \underbrace{\Delta \log (L_{iW}/L_i)}_{\text{Pct White}} + \mathbf{X}_i \beta_{gr} + \underbrace{\gamma_{m(i)gr}}_{\Delta \log (\mathbf{L}_{gr}/U_{gr}^{\theta_r})} + \underbrace{\alpha_{red(i)}}_{\theta_r \Delta \log b_{igr}} + \underbrace{\varepsilon_{igr}}_{\theta_r \Delta \log b_{igr}} \quad (11)$$

The first difference is between 1960 and 1970 using the Census microdata. CMA contains the inverted values for scaled wages ω_{jgr} and the commuting elasticities v_{gr} .

This equation is derived by combining the residential share expression (4), endogenous amenities in (6), and local highway costs in (8) where the vector of controls \mathbf{X}_i contains changes in rental prices and bins over distance from highways for the local costs (all interacted with race and education). Rents and highway costs need to be controlled for as they are correlated with changing residential choice, commuter access improvements, and changing demographics.²⁶ To obtain cleaner variation in the Interstate shock, all the previous geographic features of historical roads, railroads, etc. as well as the [Borusyak and Hull \(2023\)](#)-proposed control for CMA are also in \mathbf{X}_i . All controls are interacted with race and education.

²⁵This process is isomorphic to taking the workplace fixed effect from the “gravity” equation estimated later. Unlike [Ahlfeldt et al. \(2015\)](#) which lacks wage data, making inversion a necessity to infer determinants of workplace choice, I observe wages by race and education at employment locations. Confirming evidence from [Severen \(2021\)](#) and [Kreindler and Miyauchi \(2022\)](#), wages do not fully determine workplace location decisions. The scale parameter T_{jgr} is another determinant that captures variation in the size of the POW Zone units and workplace amenities beyond wages that are differential by group across locations, including discrimination.

²⁶As commuter access increases closer to highways, it is correlated with the localized costs of highways, and it may not be immediately clear there are enough sources of variation for identification. By controlling for the distance bins, identification of the effects of commuter access comes from comparing neighborhoods by highways that experience minimal commuter access changes, e.g. closer to the central city, to neighborhoods by highways that experience large commuter access changes, e.g. in the suburbs.

Since multiple cities are pooled together in estimation, CBSA by group fixed effects $\gamma_{m(i)gr}$ are included to capture factors such as changes in average welfare U_{gr} and aggregate population L_{gr} such as migration across cities, leading the variation to come from within cities. Importantly, this equation also contains redlining fixed effects $\alpha_{red(i)}$ to compare within neighborhood types (redlined vs. non-redlined) as in the previous empirical evidence, I found that Black households faced spatial frictions across types. The estimated ρ_r parameter then more closely represents racial preferences since within integrated, redlined areas, discrimination is less significant.

OLS results with all controls described above are presented in Table 3 Column 1. Standard errors are clustered by tract with Conley (1999) standard errors in brackets. Estimates of the residential elasticity for Black households are 0.119 (0.172) and smaller than the value of 0.802 (0.183) for White households, in line with the stylized facts indicating lower Black responsiveness.

White households have strong preferences for living in more White neighborhoods with an estimated value of $\tilde{\rho}_W = 1.049$ (0.024) while Black households have weaker preferences against living in more White neighborhoods with $\tilde{\rho}_W = -0.364$ (0.055), consistent with Bayer et al. (2007) (although with larger magnitudes for White families). In Column 2, I add controls for average income, home values, percentage high school graduates, bottom/top income quintile. These covariates lower how much Black households care about racial composition, so some of the earlier estimate came from preferences for SES correlated with race. However, the estimated values for White households are unchanged, so their preferences are mostly related to race.

These results are similar when limiting the sample to only redlined neighborhoods, as shown in Supp. Appendix Table A.2.

Moreover, instruments are needed for consistent estimation of the parameters. For θ_r , the variable $\Delta \log CMA_{igr}$ is endogenous and needs to be instrumented with $\Delta \log CMA_{igr}^{Plans}$, $\Delta \log CMA_{igr}^{Rays}$, which are the same measures as in the empirical evidence section. For ρ_r , omitted variable bias is a concern as the error term ε_{igr} corresponds to changing location characteristics not yet included as covariates. As an example, policies targeted to particular populations, such as steering by real estate agents, affect residential choice and are correlated with changing racial composition. Exogenous shifters of racial composition are then needed, and I construct two types of instruments that exploit *only variation from the highway shock*. The identification assumption behind the racial preferences parameter is then the same as for the rest of the highway parameters: that the empirical strategy isolates exogenous variation in Interstate placement.

The first type follows the 3-step approach of Davis et al. (2019). In an initial step, I estimate a simpler version of Eq. (11) that has only the residential elasticities θ_r (no endogenous amenities) as the estimand while instrumenting for CMA changes with the plans/ray network. Next, using the estimated elasticities by race, I solve a pared-down version of the model that shuts off equilibrium adjustments to predict shifts in racial composition from the highway shock. Central areas that

White families migrate from are those with the largest predicted changes in percent White. In the final step, I use the predictions for racial composition $\Delta \log(\widehat{L_{iW}}/L_i)$ as instruments. Leveraging the migration responses to CMA changes, the second type of instruments directly uses the group-specific CMA measures $\{\Delta \log CMA_{iLB}^{IV}, \Delta \log CMA_{iHB}^{IV}, \Delta \log CMA_{iLW}^{IV}, \Delta \log CMA_{iHW}^{IV}\}$ with $IV = Plans$, or $Rays$ as instruments. Since households migrate as group-specific CMA changes, then racial composition changes, and the instruments have a first-stage. Additional information on how the instruments are constructed is in Supp. Appendix E.2.6.

Table 3: Residential Elasticity and Racial Preferences

	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta \log L_{igr} (\Delta \text{Log Population } 1960\text{--}1970)$					
	OLS		IV Davis		IV CMA	
Variables	Base	+ SES Cont	Plans	Rays	Plans	Rays
$\theta_r: \Delta \log CMA_{igr}$						
Black	0.119 (0.172) [0.196]	0.224 (0.171) [0.196]	1.281*** (0.374) [0.626]	1.284*** (0.324) [0.585]	0.00593 (0.378) [0.672]	0.412 (0.290) [0.494]
White	0.802*** (0.183) [0.213]	0.802*** (0.183) [0.214]	0.576*** (0.167) [0.225]	0.918*** (0.161) [0.237]	0.228 (0.244) [0.282]	0.493** (0.203) [0.253]
$\tilde{\rho}_r = \theta_r \rho_r: \Delta \log \text{Pct White}$						
Black	-0.364*** (0.0546) [0.0722]	-0.283*** (0.0523) [0.0720]	-0.0616 (0.111) [0.176]	-0.0766 (0.0894) [0.147]	-0.0737 (0.151) [0.238]	-0.0418 (0.137) [0.214]
White	1.049*** (0.0244) [0.0436]	1.066*** (0.0246) [0.0434]	1.202*** (0.0556) [0.0957]	1.173*** (0.0526) [0.0939]	1.170*** (0.181) [0.221]	1.016*** (0.154) [0.193]
R-squared	0.190	0.202	0.531	0.527	0.565	0.568
SES Controls		Yes	Yes	Yes	Yes	Yes
Rounded Obs	N=56500		N=56000		N=38000	
S-W F-Stat (θ_B, θ_W)			6.45, 26.26	10.09, 28.55	5.76, 11.96	14.90, 16.98
S-W F-Stat ($\tilde{\rho}_B, \tilde{\rho}_W$)			4.26, 17.22	5.55, 18.61	2.68, 5.66	3.53, 6.02

Notes: Observations are differences over 1960–70 for tracts by race and education (restricted microdata). CBSA FE by group are included. SEs are clustered by tract. Conley SEs (1 km) in brackets. All specifications include controls for change in log rent, five 1-mile-wide bins over distance from highways built 1960–1970, geographic controls, and [Borusyak and Hull \(2023\)](#) control for CMA in large roads, all interacted with race and education. Redlining FE included. SES controls: changes in log of average income, pct high school graduate, pct bottom/top income quintile, home values, all interacted with race and education. Observations rounded to 500 for Census disclosure rules. Sanderson-Windmeijer multivariate F statistics are reported. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

In Table 3 Columns 3–6, I report IV estimates. Residential elasticities for White households are in the range of 0.228 (0.244) to 0.918 (0.161) and are higher than for Black households, except when using the [Davis et al. \(2019\)](#) instruments. Black residential elasticities are challenging to estimate precisely because of large standard errors. The most stable estimate across all specifications is racial preferences for White households, which range from 1.016 (0.154) to 1.202 (0.056)

and are highly statistically significant. Interestingly, I find that in the IV estimates, Black racial preferences are fairly weak with point estimates in the range of -0.042 (0.137) to -0.077 (0.089) and many not statistically significant. These results suggest that the previous findings on Black preferences may result from correlations with changing unobserved characteristics.

At the bottom of Table 3, Sanderson-Windmeijer multivariate F statistics for weak instruments with multiple endogenous regressors are reported and are consistently above 10 for parameters estimated for White households. For Black households, the F statistics can reach lower values, leading IV to be more biased towards OLS.

5.3 Validation Exercises

After completing estimation and parametrizing the model, I conduct several tests to validate that the model's predictions match the empirical moments. For non-targeted variables, Supp. Appendix Table A.3 shows that the relationship between changes in rent prices, racial sorting, and income with CMA improvements exhibits similar qualitative and quantitative patterns for the predicted and observed values. Supp. Appendix Figure B.4 shows the tight relationship between predicted vs observed commute flows in 1960 and 1970.

To validate the modeling assumptions, in Supp. Appendix Table A.4, I show that changes in log productivity are uncorrelated with distance from routes, so there is no reallocation of economic activity to areas by routes. This result rules out trade costs as an important channel for firm relocation because the productivity term is the residual component after removing the commuting channel of labor supply to workplaces. I do not model discrimination at workplaces because firm productivity is unrelated to redlining in either 1960 or 1970 (see Supp. Appendix Table A.5).

6 Welfare Analysis

Having estimated the set of key model parameters, I conduct several simulations to investigate the impacts of Interstate highways on welfare inequality. I leave the quantification of the role of discrimination to Section 7 since neighborhood barriers are assumed to be invariant to highway policy, so I take the constraints on residential choice as given and proceed with the welfare assessment.

6.1 The Impacts of the Interstates

Returning to the welfare impacts expression in Eq. (10), changes in commute costs, disamenities, and equilibrium outcomes are weighted by initial shares in the cross-sectional distribution and aggregated using substitution elasticities across locations. Because of the low residential elasticities of the Black population, their initial shares being centrally concentrated suggests that shocks to the urban core come close to fully determining their welfare impacts. To illustrate this result more definitively, I break down specific channels in the equilibrium framework and measure how welfare

changes when different parts are allowed to adjust.

In the equilibrium analysis, I simulate the construction of highways starting in 1960 as the reduction in commute times and the addition of localized costs along routes built from 1960 to 1970.²⁷ Across the 25 metro areas in the analysis, I calculate a weighted average with city-level population weights and report these averages as the main counterfactual numbers. Supp. Appendix F.3 lists the full set of equations for the general equilibrium system. Solving for equilibria follows the iterative procedure described by Allen and Arkolakis (2014).

To obtain the new equilibrium, I take the “covariates based approach” characterized by Dingel and Tintelnot (2023) rather than the “exact-hat algebra” approach of predicting counterfactual changes from initial observed flows (Dekle et al., 2008). I infer counterfactual changes with predicted flows generated using the estimated commuting elasticities to avoid overfitting to the considerable sparsity of the data, especially for Black households, while largely conveying patterns of commuting behavior. The predicted flows are also used to recover fundamentals in levels.

For parameters, residential elasticities are obtained from Table 3 where the elasticity for Black households is set to $\theta_N = 0.35$, lower than the elasticity for White households of $\theta_W = 0.8$. Preference parameter $\rho_B = 0$ because estimates of racial preferences were often insignificant for Black households, and for White households, $\rho_W = 1$ at the low range of the confidence intervals.²⁸ As empirically, home values did not change substantially, in the baseline counterfactual $\phi_{gr} = 0$, and I incorporate homeownership in an additional exercise to measure its importance. All model parameters are listed in Table 4.

After conducting the welfare analysis under different scenarios, Figure 5a displays the values for the change in welfare across the race and education groups. Starting from the left, the *direct impacts* ignore reallocation or equilibrium adjustments and is a transparent weighted average of the changes in commute times and fundamental amenities from the Interstate system with weights that are the initial shares at residences and workplaces.²⁹

$$d \log U_{gr} = -\kappa_{gr} \sum_{i,j} \pi_{igr} \pi_{j|igr} \underbrace{\frac{\Delta t_{ijgr}}{t_{ijgr}}}_{\text{Commute Times}} - \sum_i \pi_{igr} \underbrace{b^{HW} \exp(-\eta \text{Dist} HW_i)}_{\text{Local Costs}}$$

²⁷To conduct the simulation, I set the commuting time matrix to t_{ijgr}^{HW} where the Interstate highways are overlaid on the historical urban road network with the mode of transport weights for each race and education group set at their 1960 weights. The counterfactual therefore does not allow for changes in the mode of transport as a margin of adjustment. It is unlikely that accounting for this margin would change the ordering of the welfare impacts because Black households continue to commute with private automobiles at a lower rate than White households, even in the modern day (Bunten et al., 2022). I modify the exogenous amenity parameters $b_{igr,1960}$ to include the localized costs from the highway such that $b_{igr}^{HW} = b_{igr,1960}(1 - b^{HW} \exp(-\eta \text{Dist} HW_i))$ with full decay at 5 miles.

²⁸Larger values tend to create convergence issues. With these parameters, solving for counterfactuals with the iterative procedure leads to uniform convergence. Given the magnitude of these parameters, the sufficient conditions for uniqueness are no longer satisfied. See Supp. Appendix F.4. However, the conditions are not necessary for uniqueness, and I do not encounter multiple equilibria with the smaller preference parameters.

²⁹A derivation that starts from the welfare equation (7) is available in Supp. Appendix F.1.

Table 4: Key Model Parameters

Parameters	Source
<i>Labor Supply Elasticity</i> $\phi = 3$	Ahlfeldt et al. (2015), Monte et al. (2018), Morten and Oliveira (2018), Severen (2021)
<i>Commuting Elasticity</i> $v_{LB} = 4.20, v_{HB} = 3.65, v_{LW} = 4.71, v_{HW} = 4.15$ $\kappa_{LB} = 1.4, \kappa_{HB} = 1.22, \kappa_{LW} = 1.57, \kappa_{HW} = 1.38$	Estimated in Table E.14 Implied with $\phi = 3$
<i>Residential Elasticity</i> $\theta_B = 0.35, \theta_W = 0.8$	Estimated in Table 3
<i>Racial Preferences</i> $\rho_B = 0, \rho_W = 1$	Estimated in Table 3
<i>Non-Housing Consumption Share</i> $\beta_{LB} = 0.66, \beta_{HB} = 0.78, \beta_{LW} = 0.70, \beta_{HW} = 0.79$	Calibrated to CEX in Appendix E.2.3
<i>Highway Localized Costs</i> $b^{HW} = 0.203, \eta = 0.612$	Estimated in Table E.18

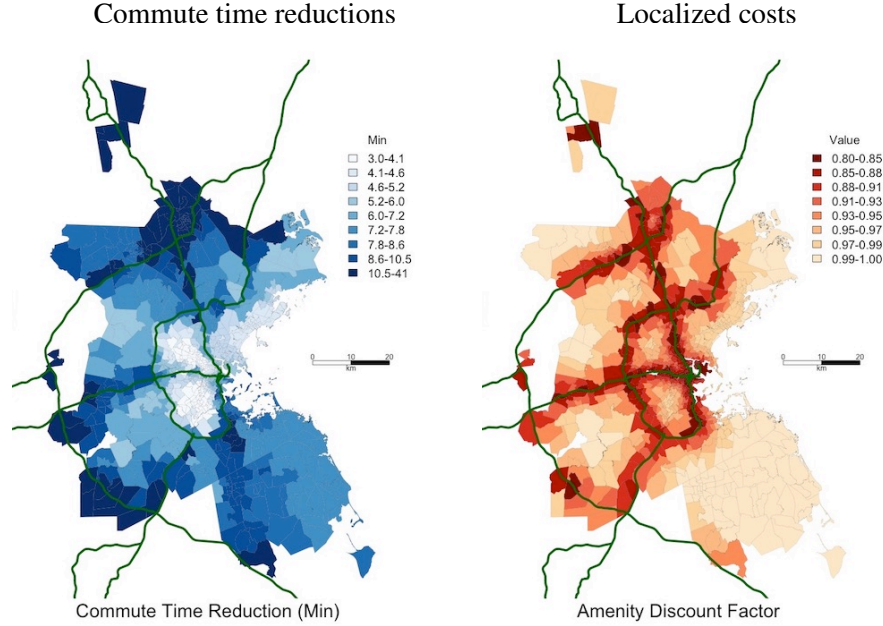
Notes: ϕ is set to a value from the literature. Parameter v_{gr} comes from Table E.14 Panel B. θ_r comes from the midpoint of estimates in Table 3. ρ_B is set to 0 since the estimates from Table 3 are not distinguishable from zero. ρ_W is set to be within the lower range of the confidence intervals from Table 3 and not greater than 1. β_{gr} comes from Table E.17. b^{HW} and η come from fitting two values in Table E.18 Column 5.

These direct impacts are visualized in Figure 5 for the city of Boston where the spatial distribution of the Black population is also provided for comparison. Given the disparate placement of highways (leading to unequal distribution of costs) as well as lower Black car usage and commute time reductions being muted in the central city (leading to unequal receipt of benefits), it is unsurprising that the welfare changes are more positive for White households. Gaps are small across education within race, but large across race. Direct impacts are around -1.5% for the Black population (slightly lower for the less-educated) and 1.7% for the White population (slightly higher for the more-educated).

Next, I allow for household *reallocation* across locations, but no equilibrium outcome adjustments, so that the only forces at play are the changes in fundamentals as well as the elasticities for residential and workplace choice. This exercise is operationalized by setting the hat $\hat{x} = x'/x$ of equilibrium outcomes to one in Eq. (10). By allowing for spatial mobility, welfare losses are then around -1% for the Black population and gains are 3% for the White population. Compared to the direct impacts, the reallocation-only impacts are much more positive for White households. As they migrate both towards positive and away from negative aspects of the highway shock, they enlarge their gains relative to the Black population and widen racial inequality.

As most of the empirical evidence was related to residential changes, I only allow equilibrium

Figure 5: Interstate Highway Impacts for Boston Metro Area in 1960



Notes: Observations are census tracts limited to those where population is observed in 1960 in IPUMS-NHGIS. Commute time changes calculated as the difference between commute times for the historical road network and for the entire Interstate network overlayed on the historical road network. Local costs are calculated by taking the parameter estimates from Table 4 and applying it to census tracts using the distance from the tract to the nearest Interstate.

outcome adjustments for residential characteristics and shut down those on the firm side in a *partial equilibrium* counterfactual. Any changes in labor supply do not affect wages paid to workers or housing demand from firms (see Supp. Appendix F.2 for exact equations). I find that the welfare results look broadly similar. Relatedly, moving to the full *general equilibrium* system only slightly changes the values, suggesting that equilibrium outcome adjustments play a small role in welfare. This lack of effect can be due to outcomes offsetting each other, e.g. White households who re-allocate to suburbs pay higher housing prices (lowering utility) but also live in more segregated neighborhoods (raising utility), canceling out overall.

Finally, incorporating *homeownership* increases inequality across race groups but does not greatly affect inequality across education groups. Welfare for the Black population declines further relative to the general equilibrium counterfactual from -1% to -1.3% while White welfare increases from 2.9% to 3.1% . Because rents increase in more affluent areas that White households reside in and decrease in integrated neighborhoods, re-distributing rents to homeowners enlarges the racial gap in welfare.

Additional Results – In Supp. Appendix Table A.6, I probe how the changes to welfare are affected by slight modifications in key parameters. Removing White homophily preferences or agglomeration forces do not substantially alter the results. Increasing homophily for Black households some-

what offsets the losses from Interstate development, since racial segregation increase. Raising the residential elasticity to larger values found in the literature boosts the welfare gains for all groups, but especially for Black households, which suggests that increasing residential mobility across all locations could be another policy solution for reducing racial disparities.

In the same table, I conduct counterfactual exercises on alternative designs for transportation infrastructure could be informative for policy. I find that welfare changes when Interstates are built according to the planned routes are similar to the original impacts. Gains are larger with the ray network as Interstates, which removes beltways that contribute less to commute time reductions but substantially increase costs. Yet, all routes lead to unequal impacts by race because Interstate highways were required to intersect central cities, further highlighting the importance of residential barriers, and because of differences in car usage. Mitigating highway costs (calculated as only including the commuting benefits) increases welfare, especially for Black households, which suggests that an effective policy would be reducing highway harms. Indeed, regulation of Interstate construction has strengthened over time to limit the negative consequences, leading to rising construction costs ([Brooks and Liscow, 2020](#)).

Lastly, Supp. Appendix Table [A.7](#) shows the changes in equilibrium outcomes from the simulations. Black households experience large drops in amenities, slightly lower wages, lower commute times, but increased commute distance. They move marginally further outwards and away from redlined areas. White households experience smaller drops in amenities, and they move substantially farther from the central city and from redlined areas. They respond more to the commute benefits by increasing their commute distances more than Black households. These equilibrium adjustments, in addition to the direct impacts, contribute to inequality in highway impacts.

7 Residential Barriers in Welfare Impacts

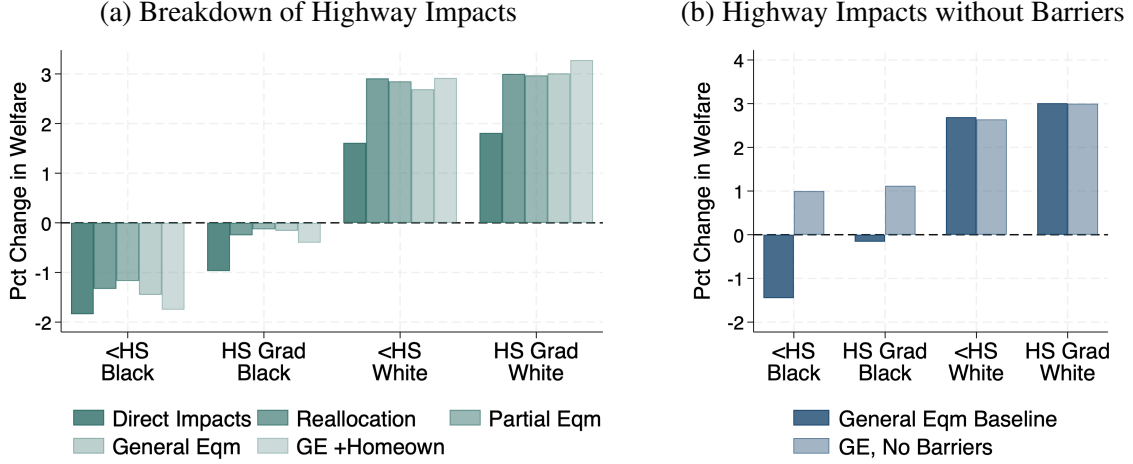
In this section, I decompose the factors behind the spatial concentration of Black households in central areas. The location-specific barriers that affect the cross-sectional distribution further shape the distributional impacts of the Interstates. I begin with differences in racial composition around the borders of redlining maps where an identification strategy permits clean tests of the presence of residential discrimination. I then discuss the takeaways from this strategy and consequently examine barriers away from the border to study segregation more broadly.

7.1 Evidence from Border Discontinuity

Returning to the model-implied barriers in the location-race-specific wedge, I employ a discontinuity design to test how they are related to the borders of the HOLC maps.

Past research has measured how racial composition sharply shifts across the grades of HOLC maps ([Hillier, 2003](#); [Faber, 2014](#); [Aaronson et al., 2021](#)). In Supp. Appendix Figure [B.5](#), percent

Figure 5: Welfare Changes (%) by Race and Education



Notes: Welfare calculations use Census restricted microdata in 1960. Direct impacts from linear approximation in Section F.1. GE simulation allows firms/wages to respond relative to PE simulation. The general equilibrium simulation with no barriers adds highway impacts to the counterfactual world with barriers removed.

White drops by a sizable 18 percentage points upon crossing into redlined neighborhoods. Yet instead of solely studying empirical changes in racial composition, I use the previously estimated parameters and model structure to infer the *sources* of segregation. The differences in racial composition at the border are NOT due entirely to discrimination because rental prices are lower in redlined areas, contributing to economic segregation correlated with race, and racial preferences would further reinforce any sorting at the border. I consequently decompose the population changes by race as resulting from various components: prices and commuting access, racial preferences, other SES characteristics, and the discriminatory wedge ($1 - \tau_{igr}^b$) as the residual.

The border discontinuity design is estimated separately by race in the 1960 Census microdata:

$$Y_{igr} = \alpha_{gr} + \psi_r D_i^{red} + \mathbf{F}_r(DistRED_i) + D_i^{red} \times \mathbf{G}_r(DistRED_i) + \lambda_{ilr} + \xi_{igr}$$

In this equation, α_{gr} are education by race fixed effects, D_i^{red} is an indicator for being a redlined neighborhood, and λ_{ilr} are fixed effects for each border l . $DistRED_i$ is the distance to the nearest border between redlined and non-redlined neighborhoods (and is positive if in a redlined one). \mathbf{F}_r and \mathbf{G}_r are polynomial functions of distance. To avoid confounding the effect of social barriers with physical barriers or changes in school districts, I remove areas by railroads, large roads, highways, and school district borders (which come from the National Center for Education Statistics).³⁰ In estimation, I follow [Calonico et al. \(2014\)](#) to calculate optimal bandwidth.

³⁰The sample is limited to tracts at least 0.1 miles away from historical large urban roads, constructed highways in 1960, or historical railroads and also at least 0.1 miles away from a school district boundary where school districts come from the 1989-1990 school year, the earliest year with district maps from NCES.

Y_{igr} corresponds to several outcomes for the factors behind residential choice. As the first outcome, $\log L_{igr}$ is informative of how each race group is distributed across the border. In Table 5 Columns 1 & 5, I find that the combination of Black households living more (a striking 1.43 (0.23) increase in log population) and White households living less (a -0.55 (0.12) decline in log population) in redlined neighborhoods leads to the drop in percentage White entering redlined areas. During this time, Black households were heavily concentrated in redlined areas.

To remove the price and CMA components from residential location $\log L_{igr}$, the next outcome is the amenity term B_{igr} , which is inverted for using the residential choice expression in Eq. (9). In Columns 2 & 6, I find the discontinuity is only slightly reduced for Black households to 1.37 (0.24). As White households also prefer lower prices, the estimate of -0.60 (0.11) is reduced as well. These results show that cheaper rents cannot explain why White households live less in redlined areas or much of the change in Black and White populations over the border.

To remove racial preferences i.e. homophily from location choice, I next invert for the fundamental amenities b_{igr} , which includes the residential wedge for discrimination.³¹ When fundamental amenities are the outcome in Columns 3 & 7, the discontinuity remains large for Black households at 1.266 (0.209) and disappears for White households to 0.0031 (0.097). This change from Column 6 to 7 implies that racial preferences fully account for why the White population does not live in redlined areas. Moreover, the insignificant coefficient in Column 7 indicates that discrimination does not affect White residential locations. Yet, racial preferences only explain a portion of the rise in the Black population, leaving a large residual in Column 3.

Importantly, measuring how fundamental amenities look along the border also provides a test of the identification assumption behind the discontinuity design, which is that other neighborhood features (minus prices, CMA, racial composition) should be smooth by the border in the absence of discrimination.³² As the discontinuity estimate in Column 7 is essentially zero for White households, neighborhoods at the border do not appear to be substantially different, and the identification assumption is satisfied.

Adding socioeconomic controls in Columns 4 & 8 does not change the results for White households and lowers the discontinuity for Black households to a still sizable value of 0.914 (0.181). For Black households, based on these estimates, 65% of the population rise entering redlined areas is in the residual wedge and thus a result of discriminatory barriers.

³¹To obtain the most conservative value for the location wedge, when inverting for fundamental amenities, I take the highest estimates for racial preferences for both White and Black households and also take the highest residential elasticity for White households and assign it to Black households. Parameters are listed at the bottom of Table 5.

³²This identification assumption is distinct from that of Aaronson et al. (2021), which searches for borders where there were no pre-existing racial differences before the maps were drawn in 1932, as they aim to measure the treatment effects of the HOLC maps. The discontinuity estimates of this paper capture discrimination that is not only from the drawing of the HOLC maps.

Additional Results – To further test the identification assumption, in Supp. Appendix E.2.7, I assess if natural amenities change discontinuously along the border. I find that those which are less manipulable, i.e. open water and wetlands, are continuous, which supports the identification assumption.³³ I also conduct additional robustness checks such as decomposing the sources of segregation using controls, rather than the model structure, to reduce the reliance on the structural assumptions and estimated parameters. Finally, I examine how estimates of the discontinuity change over time, for different sample definitions, and for additional variables.

Table 5: Border Discontinuity Decomposition

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	<i>Black</i>				<i>White</i>			
Variables	$\log L_{igB}$	$\theta_B \log B_{igB}$	$\theta_B \log b_{igB}$	+ SES Cont	$\log L_{igW}$	$\theta_W \log B_{igW}$	$\theta_W \log b_{igW}$	+ SES Cont
Border RD	1.425*** (0.226)	1.370*** (0.238)	1.266*** (0.209)	0.914*** (0.181)	-0.546*** (0.122)	-0.603*** (0.112)	0.00305 (0.0971)	0.132 (0.0937)
Bandwidth (mi)	0.495	0.447	0.509	0.496	0.358	0.398	0.297	0.305
Rounded Obs	N=13000				N=13500			

Notes: Observations are census tracts by redlining-map border by race from the 1960 restricted Census microdata. Dependent variables are residualized on fixed effects for education and border fixed effects. SES Controls: log of pct high school grad, population density, average income, pct bottom/top quintile, and home values. Limited to tracts at least 0.1 miles away from physical barriers of historical large roads, constructed highways in 1960, or railroads, and also at least 0.1 miles away from school district boundaries. The bandwidth is chosen optimally following Calónico et al. (2014) with order of polynomial=1. Observations rounded to 500 for Census disclosure rules. Parameters to invert for dependent variables are $\theta_B = \theta_W = 0.9$, $\theta_B \rho_B = -0.3$, $\theta_W \rho_W = 1.20$, $\beta_{LB} = 0.66$, $\beta_{HB} = 0.78$, $\beta_{LW} = 0.70$, $\beta_{HW} = 0.79$. *** p<0.01, ** p<0.05, * p<0.1

7.2 Interaction with Interstates for Welfare Impacts

Useful conceptual lessons are gleaned from the border design. Specifically, the model-implied barriers appear to be a large determinant of Black residential choices and are correlated with empirical proxies for where discrimination historically occurred.

However, the discontinuity estimate is likely an underestimate of the extent to which Black households are excluded from broad sections of cities because the change in racial composition at the border pales in comparison to the stark segregation during this era. In 1960, 70% of census tracts are more than 99% White, and near the border, neighborhoods are more racially integrated than those in far-flung suburbs. This tradeoff between proper identification and the potential scope of the question is widespread in economics. While the border design allows for a testable identification assumption, the estimates there are a local average treatment effect that overlooks heterogeneity in discrimination further away.

³³Data on land types such as open water, wetlands, and deciduous forests come from the National Land Cover Database (NLCD), and tree cover canopy comes from the U.S. Forest Service. Interestingly, features such as tree cover and deciduous forest, which may be considered *endogenous* amenities, do differ across the border.

For the final analysis, I remove the residential wedge across all neighborhoods and re-simulate the construction of Interstate highways to measure the new welfare gains and losses. In practice, assuming that housing discrimination does not apply to the White population, eliminating barriers occurs through setting Black fundamental amenities (which contain the wedge) equal to White fundamentals (which should reflect natural amenities). Implicitly, this exercise assumes that the valuation of fundamental, natural amenities is not differential by race.³⁴ Otherwise, the location-race-residual is overstating the degree of segregation attributable to discrimination.

In this new environment, I display the changes to welfare from Interstate development in Figure 5b. The racial gap in the general equilibrium impacts from highways is greatly diminished by around 54%, so residential barriers determine the majority of inequality from the Interstate system. Black households now experience welfare gains from highways of 1%, versus previously they were facing losses of -1% . This result is explained by the substantial reduction in the spatial concentration of Black families, who now live 94% farther from the CBD and 50% less in redlined neighborhoods, as shown in Supp. Appendix Table A.8.

White households experience similar gains to before of 2.8%, so relaxing residential discrimination does not greatly alter their benefits from Interstate development. This finding notably suggests that policies which assist minority groups do not have to come at great expense to the majority group, especially given the smaller relative size of these populations. All race and education groups in this counterfactual receive large welfare improvements from infrastructure construction.

However, the gap by race in welfare impacts does not fully disappear. Partially, a gap persists because racial segregation is still present from differences in economic status, commuting patterns, and firm locations by race, as well as racial homophily by both Black and White households. Additionally, car usage by the Black population continues to be lower than for the White population, so the commuting benefits are not equalized across groups. Still, the clear takeaway from this counterfactual analysis is that segregation, specifically through forces that cannot be accounted for by economic or social factors, plays a crucial role in inequality in highway impacts.

8 Conclusion

This paper constructs several rich historical datasets and develops a quantitative framework to measure the distributional impacts of the most prominent transportation infrastructure project in the U.S., the Interstate highway system. To understand why there are profoundly unequal effects, I measure how neighborhood discrimination is a central determinant of the spatial concentration of Black families, which then interacts with highway policy to produce disparities across race. Spatial

³⁴The fundamental amenity term is a residual and could contain other location-specific differences by race not yet accounted for that would not be considered discrimination. Examples include differences in social networks or information access.

frictions that limit the mobility of minority groups and the selective placement of the Interstate network lead the benefits and costs to be shared unequally, with the most disadvantaged bearing more of the costs while garnering fewer of the benefits.

While it may seem that Interstate highways and housing discrimination are things of the past, road infrastructure expansions in the modern day encounter the same equity concerns as they have historically.³⁵ The persistence of segregation along racial and economic lines and the political disempowerment of groups of color leads the harms of critical infrastructure, such as industrial facilities, to be borne by the most marginalized populations (Currie et al., 2022). Discrimination in housing has not disappeared and continues to restrict residential choice for many groups (Bayer et al., 2021). Moreover, the radical transformation of cities brought about by the Interstate highway system has persistent effects, given the permanent nature of large-scale infrastructure.

The findings of this paper do not diminish the immense economic value of building the Interstate highway system. Indeed, every demographic group experiences large welfare gains from its development when given the freedom to live in any neighborhood of their choosing. This study suggests that more policies should improve spatial mobility for the most disadvantaged families, as residential segregation is a pivotal determinant of how equitable any placed-based intervention will be in the distribution of its costs and benefits.

³⁵ A \$9 billion highway widening project in Houston, Texas was paused by the Federal Highway Administration in 2021 after local groups opposed the expansion. The re-routing of parts of I-45 would displace predominantly Black and Latino neighborhoods as well as the original Chinatown of downtown Houston.

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