What Did Interstate Highways Do to Urban Neighborhoods?

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Abstract

Critical geographers, historians, and journalists have described the mid-century construction of urban Interstate highways as a deliberate effort to spatially marginalize or depopulate poor and racially diverse neighborhoods. But such claims have not been supported by quantitative evidence on highways' overall effect. We offer the first national-level estimates of highways' effects on population and housing stock in central cities. Combining an original highway database created from historical road atlases with historical Census and neighborhood assessments conducted for the Federal Housing Administration, we show that Interstate highways built before 1970 reduced population and housing stock by about 15 percent on average since 1960, through these effects varied and have attenuated in recent years. Highways' effects were felt most in the "redlined" neighborhoods that disproportionately suffered highway construction. Our results show that Interstates were instruments of urban renewal, but their adverse effects largely compounded ongoing losses in central cities.

To what extent have urban planners acting at the behest of elites used transportation infrastructure policy to marginalize poor and racially diverse neighborhoods? Critical geographers, historians, sociologists, urban planning scholars, and journalists, have written extensively on the instrumental uses of transportation infrastructure to remodel cities. This scholarship suggests that urban highways and mass transit are built to control urban space, sometimes by physically destroying existing neighborhoods (Scott 1998, Ch. 2), or by directing traffic towards preferred (often downtown) business districts (Fogelson 2005). From Baron von Haussmann's 1850s Paris to Robert Moses's midcentury New York, scholars have offered archetypal examples of infrastructure playing a role in "urban renewal" programs. In the United States, critics have conversed over archetypes: urban planning disasters that destroyed poor and racially and ethnically diverse "slum" neighborhoods in conjunction with redevelopment efforts to convert undesired residential neighborhoods into public facilities, high-rent commercial real estate, or housing for high-income professionals (Gans 1991). Critical scholars, especially, describe such redevelopment schemes as part of a larger capitalist project to subject cities to spatial control by a capitalist elite (Henderson 2006), depriving average urban residents of their "right to the city" (Lefebvre, Kofman, and Lebas 1996; Harvey 2008, 27) directly: by destroying their neighborhoods and putting land to the service of state-backed developers.

In the regnant view in urban scholarship, elites used urban road building and other development to exercise spatial control over marginalized groups. Influenced to a considerable degree by the writings of Jane Jacobs and Robert Caro, scholars have come to take for granted that Interstate highways—major expressways built by state governments with 90% federal funding—were uniformly ruinous to urban neighborhoods. Caro's widely read description of the damage wrought in Robert Moses's New York—most famously in his account of "One Mile" of the Cross Bronx Expressway built through a thriving working class neighborhood (Caro 1975)—has been the template for case studies of Interstates' effects in other cities and neighborhoods. From the destruction of Miami's Overtown black district (Mohl 1993), to Birmingham's use of construction of the new I-59 expressway to separate black and white neighborhoods (Connerly 2002), the literature has focused on the worst episodes of freeway planners inflicting harm on cities (Mohl 2004; Baumbach and Borah 1981; DiMento 2009; Newman and Kenworthy 1999). Kruse (2005), for example, writes that Ben Massell, Atlanta's largest landowner, endorsed construction of the I-285 Perimeter expressway to isolate the predominantly black central city from the area's growing white periphery (243). Research on the subsequent "Freeway Revolts" in major US cities has similarly focused on episodes of contention in which neighborhood groups organized to block or resist construction of expressway projects (Rose and Mohl 2012, 113–58; Avila 2014). By focusing on the most egregious episodes of Interstate construction, immediate destructive effects, and contemporaneous reaction, the existing research has not focused on typical damage inflicted by highways, nor the long-term effects of their presence in different types of urban neighborhoods. As a result, metro-level quantitative studies assessing infrastructure's adverse effects are likely to be biased towards attributing neighborhood destruction to elites' urban renewal and social control goals.

In this article, we assess whether the Interstate highway program did, in fact, produce the long term changes to urban space allegedly sought by urban elites: clearing of undesirable slum neighborhoods followed by redevelopment. Without attempting to discern elites' or planners' motivations, we demonstrate the importance of addressing such questions longitudinally: we present multi-decade quantitative estimates of Interstates' long-term destructive effects in the urban, and especially poor and racially diverse, neighborhoods in which they were built, as measured through population and housing losses. We also report the extent to which the neighborhoods affected by highway building subsequently underwent housing redevelopment. In the course of work on this project, one of our major contributions is a new nationwide historical GIS database that captures expansion of Interstate and US-numbered highways based on Rand McNally Road Atlases. Using our database in conjunction with Census historical GIS data (Fitch and Ruggles 2003; Manson et al. 2017) and recently digitized federal "redlining" maps from the 1930s (Nelson et al. 2017), we estimate highways' effects on population and housing in urban neighborhoods. Using these data, we applied matching techniques and linear regression to identify the effects of placement of Interstates on subsequent changes in housing stock and population in affected neighborhoods from 1960 to 2010. Our results demonstrate that highways severely worsened already large population losses in the neighborhoods through which they were built. Neighborhoods designated as "hazardous" on redlining maps were three times more likely than the best rated neighborhoods to be subjected to Interstate highway placement. With few exceptions, the neighborhoods in which state highway departments built Interstates suffered long-term population and housing losses that peaked in the 1980s and 1990s, diminishing only slightly by the 2010 Census. While these effects were quite large, they were in addition to secular population losses associated with general urban decline, redlining practices, and urban renewal.[1] Our results confirm aspects of the conventional wisdom, with important qualifications. Highways were an effective de facto instrument of neighborhood spatial control, but these effects were in addition to secular declines already underway in poor urban neighborhoods. To the extent highways facilitated subsequent net positive redevelopment, it was most likely to occur in neighborhoods that were more favorably rated before the building of Interstates.

Assessing Urban Highways as Spatial Policy

Scholars have regularly demonstrated how highways and other transportation infrastructure can be used to control the use of urban space. While transportation project advocates are often motivated by the goal of general economic development, they also use transportation development as a method for extending spatial control over territory. Scott famously showed that Haussmann's urban renewal projects in 1850s Paris—which including construction of wide boulevards and new worker housing—destroyed neighborhoods populated by the working class (Scott 1998). In the United States, Robert Moses's early parkway designs on Long Island were informed by Moses's progressive social reform ideology: on the one hand, the projects provided urban residents access to health-enhancing recreational opportunities, but also enabled Moses to extend his nascent urban development machine's influence over Long Island (Caro 1975). The historical record offers

[1]Other scholars have examined housing losses using similar methods to ours, often focusing on housing and urban renewal policy (Goetz 2000; Talen 2014; Hackworth 2016). A recent working paper takes a different methodological approach to assess highways' urban effects (**BriLin18**)).

numerous anecdotes of the construction and non-construction of transportation infrastructure as a point of contention, with various local elites—from local chambers of commerce to homeowners—succeeding at using transportation infrastructure to selectively shape mobility (Fogelson 2005; Schrag 2006; Fleming 2016; Geismer 2014; Wickert 2016).

Such accounts often imply that planners' intentions led to policy-driven change in urban neighborhoods. The Housing Act of 1949 intended to replace slum housing with low-income housing projects or more affluent private housing, or converting such areas to uses believed to serve the public interest, including universities (Winling 2017) and hospitals. While the prima facie evidence, from Boston's West End (Gans 1991) to Chicago's “Second Ghetto" (Hirsch 2009), indicates that such federally financed programs affected specific neighborhoods neighborhoods, neither long-run decline nor redevelopment of urban neighborhoods (where it occurred) can be attributed solely to intentional planning or federally financed urban programs. Teaford (2000), for example, has argued that the impacts of the federal urban renewal program “were never as great as some observers assumed, and its physical legacy was limited" (443).

Similar concerns apply to our understanding federally financed highways' effects in urban neighborhoods. Interstate highways, which involved greater federal funding and more urban building than prior projects, would appear to be the most likely example of infrastructure policy enabling neighborhood change. The Federal Aid Highway Act of 1956 provided generous 90% funding of Interstate projects, and could be applied to urban renewal objectives—especially “slum clearance"—in the context of property takings for road construction (DiMento 2009; DiMento and Ellis 2013). In Washington, DC, for example, planning officials obtained federal housing funds for slum clearance, then used federal highway funds to build an Interstate highway in cleared locations (Schrag 2014, 22–26).

Highways' adverse effects on cities may also be attributed to negligence of “rational" transportation planners, who were primarily concerned with the efficient movement of automobile traffic on chosen routes (Newman and Kenworthy 1999), but did little to account for highways' adverse effects in neighborhoods. But while they may have disregarded the welfare of the urban residents displaced by highway projects, efficiency concerns may have reduced adverse effects. For example, highway planners sometimes sought to minimize land acquisition costs by routing highways through parkland, industrial areas, and other unpopulated regions in a way that minimized impacts in populated urban neighborhoods (DiMento and Ellis 2013), but did not incorporate social and environmental impacts into road planning until forced to by late 1960s and early 1970s Freeway Revolts, well-organized campaigns to block Interstate projects (Mohl and Rose 2012). What studies were done during the peak Interstate construction period in the 1950s and 1960s were usually concerned with assessing economic development benefits (Goldstein 1970). Such findings, based on comparative case studies or basic interrupted time series analysis, appeared in the work of early quantitative geographers (Garrison et al. 1959) and in research compendiums assembled by the federal Bureau of Public Roads and Federal Highway Administration (United States. Department of Commerce. Bureau of Public Roads. 1964; U.S. Department of Commerce. Bureau of Public Roads. 1966; Federal Highway Administration 1966). Only a few contemporaneous observers on the periphery of the highway program, including Daniel Patrick Moynihan (1960) and Lewis Mumford (1957), vocally criticized highway planners' shortsighted practices and their failure to measure urban social costs. However, only by the late 1960s and early 1970s did social scientists and geographers begin measuring highways' adverse community effects in earnest. For example, radical geographer William Bunge pioneered a study of Detroit geography, offering some of the first measurements of Interstate highways' effects on black neighborhoods (Bunge 1971). In brief, the engineering mindset of highway planners, focused as it was on optimizing traffic movement and not on aiding urban renewal, may have minimized damage to urban centers.

Data and Methods

The regnant account of highways as an instrument of urban renewal suggests that planners and politicians were deliberate in using highways as an instrument of urban renewal, and targeting neighborhoods for highway development. To the extent that highway planners considered known factors in deciding where to build Interstates, biases in the placement of highways present a manageable causal inference problem. Federal guidelines advising states on best highway construction practices allow us to observe, and account for, the measurable factors used to determine placement of highways—the “assignment mechanism" (Rubin 1991). Our data collection and statistical methods for causal identification are built around modeling this process. We created a new urban neighborhood geography based on available historical Census and redlining maps.

We estimated the causal of effect of highways construction on two major outcomes measured in the Census: housing stock and population. Among available measures, these two variables most clearly and consistently capture neighborhood change.[2] Because highway planners were more likely to place Interstate highways in some neighborhoods than others, we adopted a causal identification strategy to account for subjective elite perceptions and neighborhoods' demographic and physical makeup. To account for the assignment mechanism, we used these covariate data in subclassification (exact matching) followed by entropy balancing. On the resulting reweighted sample, we applied least squares regression, including as predictors the same variables included in the matching procedure (Ho et al. 2007).

To historical record provides ample documentation of the factors considered in determining the location of Interstate highways. The 1944 *Interregional Highways* report, which presented the first proposal for what would become the Interstate Highway System, laid out criteria to be considered in the location of a national expressway system, and the specific factors that would determine intercity and county route selection. These factors have been used in previous work estimating the effects of the density of the highway network built in suburban counties and across metropolitan areas (Nall 2015, 2018). However, unlike previous studies, which have tended to focus on larger metropolitan areas, our study has required us to attend to ways that state and local elites might have sought to use highways to benefit preferred constituencies at the expense of less favored ones (Glaeser and Shleifer 2005). Data on neighborhoods' demographic makeup and the subjective rating of specific neighborhoods by local elites—captured by HOLC redlining maps—account for bias against specific places and constituencies. Therefore, our data collection strategy aims to

[2]The clearest indicator of neighborhood desirability, home value, was recorded inconsistently across our study's time period, and became available only with the 1970 Census.

account for both technical and political factors leading to highway construction in a residential location, using measures collected before construction of Interstates.

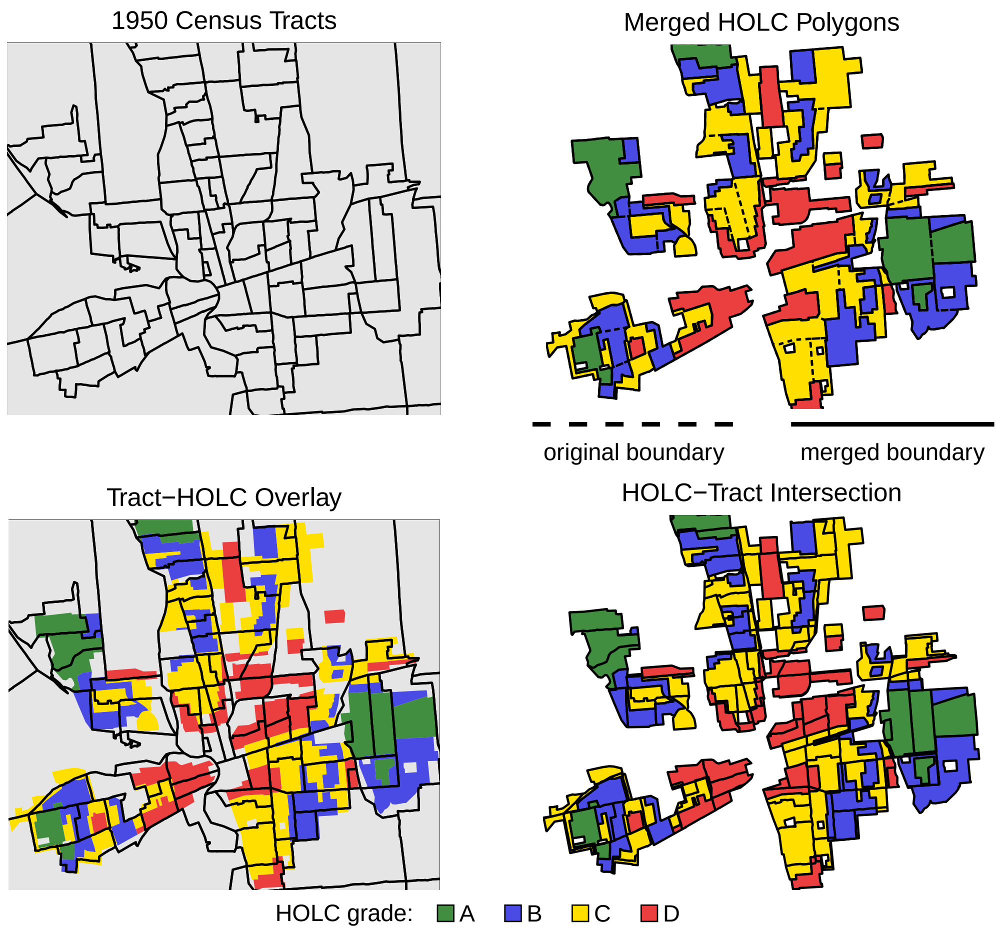
Defining Neighborhoods for Purposes of Historical Comparison

To make use of available data on neighborhood characteristics from the pre-treatment period, we defined our population of interest as all urban neighborhoods that were covered by the Home Owners Loan Corporation (HOLC) residential security maps drafted in the late 1930s, and for which 1950 Census tract data were also available. This definition includes most residential neighborhoods in the most central parts of present-day major cities. In defining these neighborhoods, we took care to analyze only neighborhoods that were assigned evaluations on the HOLC maps. These assessments, made by Federal Housing Administration (FHA) surveyors, gave residential neighborhoods creditworthiness scores on a four-point scale running from A (best) through D (worst). The neighborhood scores informed the agency and bankers about each home's perceived suitability for federal mortgage guarantees and refinancing (Jackson 1985, 202–3). These data were recently converted to into analyzable GIS vector data and published by a consortium of urban historians and digital humanities scholars (Nelson et al. 2017). We combine the HOLC map information with Census data from subsequent decades, 1950 to 2010.[3]

Because the HOLC map geographies do not align perfectly with Census tract data, and because Census tracts vary by year, for our analysis we define a new interpolated unit called the *HOLC-tract*, which consists of portions of 1950–2010 Census tracts that appear in the National Historical GIS database (Manson et al. 2017) and that share a common HOLC letter rating. All GIS data from subsequent years are standardized to these tract sections to allow comparisons over multiple decades.

The process for creating HOLC-tracts is outlined in Figure 1, which presents HOLC neighborhoods and Census tracts in Columbus, Ohio. The top left panel presents all 1950 Census tracts in the metropolitan area. Many of these cover commercial, industrial, and undeveloped areas that

[3]Separately, we collected and merged in Census tract data from 1940, but those tract-level data were available for neighborhoods in only the largest US cities.



Treatment type	HOLC grade	*N*	Area (sq km)	% of units	% of area	% treated	% area treated	% treated units	% treated area
Built pre−1960, no buffer	A	13	18	0.11	0.32	1.86	3.05	2.15	4.40
	B	82	66	0.71	1.16	3.42	5.07	13.53	16.03
	C	266	203	2.31	3.58	5.51	8.22	43.89	49.27
	D	245	125	2.13	2.20	6.85	9.51	40.43	30.29
Built 1960−1969, 400 m buffer	A	48	47	0.47	0.95	7.56	8.92	3.30	5.73
	B	203	155	1.99	3.07	9.39	13.12	13.96	18.59
	C	628	388	6.15	7.67	14.55	17.72	43.19	46.39
	D	575	245	5.63	4.84	18.56	21.35	39.55	29.29
Built pre−1960, no buffer	A	23	30	0.20	0.52	3.24	5.00	3.16	5.17
	B	76	56	0.65	0.96	3.18	4.35	10.43	9.61
	C	284	286	2.44	4.89	5.86	11.21	38.96	48.93
	D	346	212	2.98	3.63	9.40	15.17	47.46	36.29
Built 1960−1969, 400 m buffer	A	56	53	0.55	1.04	8.71	9.93	3.75	5.64
	B	198	125	1.93	2.42	9.18	10.85	13.25	13.11
	C	564	449	5.50	8.68	13.26	19.97	37.75	47.02
	D	676	327	6.59	6.32	21.13	26.63	45.25	34.23

Figure 1: Creation of the HOLC-tract units used in analysis, using Columbus, Ohio as an example. Home Owners Loan Corporation polygon files (Nelson et al. 2017) were merged with the NHGIS 1950 Census tract polygons, for which data were areally interpolated for later Census years. Key summary statistics by HOLC grade are reported in the table.

were not assigned grades on the HOLC maps, and were therefore excluded from our database. The top right panel presents the full set of graded HOLC areas, showing how contiguous and identically rated HOLC polygons merged into single polygons to simplify subsequent merging with Census data.[4] The bottom left panel presents the same tract map overlaid on the merged HOLC areas. While the graded areas on the HOLC maps nearly always overlapped 1950 Census tracts, tracts sometimes contained parts of differently graded areas, and vice versa. The bottom right panel displays the final HOLC-tract sample.[5]

For any given Census year, values for HOLC-tract h of a count variable c are calculated as follows:

$$A_h \sum_{i=1}^{N} \frac{1}{a_i} \times \sum_{i=1}^{N} \left(c_i \times \frac{a_i}{A_i} \right) \tag{1}$$

Where i indexes Census tracts that intersect with the HOLC-tract, h, and have a non-missing value for c. N is the total number of such Census tracts in some year t (if t is the reference year, $N = 1$, $A_h = a_i$, and the equation simplifies to $\frac{v_i \times a_i}{A_i}$). a_i is the area of i that intersects with h, A_i is the total area of tract i, and A_h is the total area of HOLC-tract h, $h \geq \sum_{i=1}^{N} a_i$.[6]

[4] Maps in the University of Richmond HOLC archive sometimes included “area descriptions," the HOLC surveyors’ canvassing forms used to rationalize neighborhood ratings for each neighborhood. However, these valuable data were missing for many HOLC areas.

[5] We assume uniform distributions within Census tracts, a widely used assumption in basic areal interpolation methods. For example, if half of a Census tract overlaps with a HOLC-tract, we assume that half of the tract’s population and housing units are in the resulting HOLC-tract. Because HOLC-tracts are based on 1950 Census tracts, no additional interpolation is necessary for 1950 Census values. However, for Censuses other than 1950, parts of the HOLC-tract may not overlap with Census tracts, or some tracts may be missing data. In such instances, we extrapolate known values to fill the area of the HOLC-tracts. For example, if half the area of the HOLC-tract was filled by a single Census tract but otherwise devoid of Census data, we doubled the tract’s Census count values. We adopted a rule to drop HOLC-tracts that were 5% or less of the area of the applicable 1950 Census tract. To ascertain the robustness of the coding rules, we conducted additional robustness checks setting different thresholds for data exclusion. Our analyses are robust to these coding choices (Online Appendix, p. 16).

[6] We adopt an areal interpolation method focused on the features of our data. Leading constant-geography databases begin, at their earliest, in 1970, the first year that the Census Bureau tracted the entire country. To our knowledge we are the first researchers to apply areal interpolation to a national database of HOLC neighborhoods to allow long-term comparisons. All areal interpolation methods entail introduction of error that depends on the researcher’s chosen source and target (output) data (Schroeder 2007, 2017; Logan, Xu, and Stults 2014; Hawley and Moellering 2005). The most accurate methods typically capitalize on auxiliary data, such as land use data and road network density (which proxies for population density), that improve on the uniform distribution assumptions, but such fine-grained data are often unavailable in historical settings.

Treatment

Our treatment variable is a binary indicator of whether an Interstate expressway was built in a HOLC-tract in one of two construction periods. We assembled our treatment data from georeferenced Rand McNally Road Atlases from the years 1960 to the present. We assembled our data by starting with US-numbered and Interstate highways in the 2011 Bureau of Transportation Statistics National Highway Planning Network (NHPN) layer (Federal Highway Administration 2013). For each segment in these data, we used the Rand McNally road atlases to assign each included NHPN segment additional data fields by assigning each segment the class of road reported in the Rand McNally atlases from 1934 and from 1940 to 2000 (at decade intervals). Following the approach in Nall (2015), we define a HOLC-tract as being treated during a specific decade if the district had any Interstate mileage in the chosen decade, and none before, and separately calculate highways' effects in each cohort. To ensure that we are making fair comparisons across the 50 to 60 years after Interstate construction, we define and make comparisons within two treatment *cohorts*: HOLC-tracts in which Interstates had been built by 1960, and others in which Interstates were built between 1960 and 1969. This captures the majority of Interstate construction. (So few urban Interstate miles were completed in the 1970s that any attempted estimates, especially within neighborhood subgroups, would be severely underpowered.)[7] In each of the evaluation cohorts, HOLC-tracts were defined as treated only if an Interstate highway directly intersected the HOLC-tract.[8] For purposes of estimating the average treatment effect on the treated units, the data set used in estimation contains only the HOLC-tracts "treated" during that cohort, plus those not treated in previous or subsequent period.

To get a sense of how highway placement varied by HOLC grade, one can consult the table at the bottom of Figure 1. For each treatment cohort (built pre-1960 vs. built 1960–1969) and buffer type (no buffer vs. 400 m buffer), the table displays: the total number of HOLC-tract units

[7] Among the HOLC-tracts in the database, only 4% had highways built in 1970 or later. This prevented precise estimation of highways' causal effects, especially for subgroup analysis.

[8] As a robustness check, our treatment variable was recoded by placing a 400-meter buffer around Interstates, and all HOLC-tracts intersecting with the buffers were defined as treated. Using the buffered treatment variable yields approximately the same results. (See Online Appendix, p. 9.

of that grade that were treated according to that definition (*N*); the total area in square kilometers corresponding to those treated units (Area); the percent of all units N corresponds to (% of units); the percent of total area that the treated area of that HOLC grade corresponds to (% area); the percent of HOLC-tracts of that grade that were treated according to that definition (% treated); the percent of area from HOLC-tracts of that grade that were treated according to that definition (% area treated); the percent of treated units in that subset it represents (% treated units, which sums to 100 within the subset); and the percent of treated area it represents[9] For example, about 1.9 percent of A-rated, 3.4 percent of B-rated, 5.5 percent of C-rated, and 6.9 percent of D-rated HOLC-tracts were coded as treated before 1960 (without applying a buffer). Within this subset, A- and B-rated HOLC-tracts represent about 20.4 percent of the total treated area, while C- and D-rated neighborhoods account for 49.3 and 30.3 percent of the treated area, respectively. Regardless of the treatment cohort or whether a buffer was applied, lower-rated neighborhoods were much more likely to receive Interstates.

Outcomes

We focus on two longitudinally comparable and clear-cut measures of Interstates' effects on HOLC-tracts: population and number of housing units in each Census year, measured as *log persons per square kilometer* and *log housing units per square kilometer*.[10] Destruction of housing units for highway rights of way is the most direct localized impact that we can measure in Census data. However, even where highway planners sought to minimize destruction of housing stock in a neighborhood, neighborhoods in the vicinity of a highway may have lost housing as Interstates' noise, air pollution, and other nuisances. Absent other financial data (such as home values), a decline in the number of housing units provides the clearest indicator that Interstates destroyed neighborhood capital stored in housing stock. While population is highly correlated with housing unit count ($r > .9$), it provides independent information on Interstate's impacts. We track these

[9] This was the % treated area, i.e., $100 \times$ % area treated $\div \sum$[% area treated], where $\sum$[% area treated] $= 100$).

[10] To account for instances of tracts with zero population, we added 1 to all values.

population and housing unit values for all HOLC-tracts for every decennial Census year from 1950 to 2010.

In addition to analyzing the effects on urban development, we draw upon additional Census data to assess how changes in housing and population coincided with other forms of residential change. The Census “year structure built" variable has indicated the number of housing units built in each decade, and has been reported since the 1970 Census. It captures two important outcomes: effects of highway construction on the net removal of old housing stock, and the presence of newer housing stock. Presence of relatively newer housing stock is an indicator of the extent to which neighborhoods became an attractive site for new housing development. Even if state highway departments destroyed housing stock when building Interstate highways, the possibility remains that the new highways could have stimulated economic activity in portions of affected neighborhoods outside the highway’s immediate footprint. To capture the extent to which highways destroyed preexisting housing and stimulated (or inhibited) development, we examine Interstates’ effect on the number of housing units in HOLC-tracts built in specific decades. This analysis decomposes the factors contributing to growth or decline in housing units. If highways caused a drop in older housing units and an increase in newer housing units over time, this would suggest that highways’ long-term impacts were most clearly felt through their role in “slum clearance." If, instead, highways caused a drop in older as well as newer units, it would indicate that destruction of housing units for highway construction was accompanied by subsequent disinvestment in affected neighborhoods. Finally, minimal loss of pre-Interstate housing stock followed by ongoing drops in production of newer housing units would suggest that highways’ adverse effect on housing occurred primarily through discouraging real estate investment.

We examined other outcomes, including the percentage nonwhite (racial minority), the proportion of housing units rented, and median home values. These supplemental results appear in the Online Appendix, p. 23.

Covariates

For each HOLC-tract, we assembled data on baseline factors believed to predict construction of Interstate highways and influence our outcomes of interest: subjective ratings of neighborhoods' desirability and quality; baseline demographic characteristics; and preexisting infrastructure and physical features conducive to highway construction. The state highway departments that had jurisdiction over Interstate roadbuilding employed transportation engineers concerned with planning routes that maximized efficient traffic flow in response to expected point-to-point traffic demand, usually without regard for environmental and equity concerns (Mickle 1952; Mohl and Rose 2012). Thus, urban Interstate route locations typically were constructed to offer the least resistance to roadbuilders (in financial cost and political controversy) while also preserving routes' directness (United States, Public Roads Administration 1944; Taylor 1995). While transportation engineering practices might have led to more highways in poor neighborhoods, strict adherence to federal guidelines might have resulted in alternative routes. As DiMento and Ellis (2013) write, *Interregional Highways* advised that the new highways should be located "parallel to the normal street grid", "near or above railroad rights of way," along "riverbanks and the valleys of small streams," or "along the boundaries of parks and other large tracts of city or institutional property" (64). Such cost-saving location decisions could have placed highways between neighborhoods, minimizing long-term neighborhood damage and housing loss.

While rational transportation planners (Newman and Kenworthy 1999) were not concerned with using highways as instruments of urban renewal and social control, even nominally race-blind, fiscally conservative engineering practices may have resulted in de facto discrimination against racially diverse neighborhoods. Throughout the 1950s and 1960s, residents of poor and racial minority neighborhoods lacked the political and legal power required to block slum clearance. Such neighborhoods also had a higher share of renters who, all else equal, are less likely to vote (Manturuk, Lindblad, and Quercia 2009) or to attend public meetings to challenge development projects (Einstein, Palmer, and Glick 2018). Renters had few rights against property seizures, and federal law did not require state highway departments to provide (minimal) relocation assistance to renters until 1965 (Mohl 2004, 680). Finally, poor and racially diverse neighborhoods had been economically weakened by redlining—decades of financial, insurance, and real estate practices that denied capital to, entire urban neighborhoods, as a matter of law (Rothstein 2017) and commercial practice (Jackson 1980; Jackson 1985; Hillier 2003).

For each HOLC-tract, we collected baseline covariate data, starting with *HOLC residential security map ratings*. The residential security maps created by the Home Owners Loan Corporation (HOLC)—the agency responsible for rating neighborhoods for refinancing of home loans for homeowners in default during the New Deal era—can be understood as a summary statistic capturing the probability that a neighborhood will be subjected to disinvestment, slum clearance, urban renewal, and, after accounting for technical and physical factors, highway construction. A large collection of HOLC maps were recently digitally traced and converted to shapefiles by a multi-university research consortium (Nelson et al. 2017). We downloaded and combined the data from the 58 cities for which the consortium reported data.[11] In addition to relying on demographic data, HOLC auditors conducted surveys of bankers, city building officials, and other holders of local expert knowledge to determine how to assign ratings to various neighborhoods, which were given ratings from "A" (most desirable and creditworthy) to "D" ("hazardous"). The presence of people of color or certain Southern or Eastern European groups factored into the ratings. Even limited settlement by blacks, Asians, or other racial and ethnic groups could place a neighborhood in the "D" category. The ratings also favored recently developed, single-family residential neighborhoods, to the exclusion of mixed-use neighborhoods with multi-family units and depreciating older homes (Federal Housing Administration. 1936).[12]

While the causal effect of HOLC maps on institutions' behavior has been debated by urban historians, the maps nevertheless are a useful summary of official assessments of neighborhood

[11] GeoJSON files used to create the online map were imported into ArcMap and combined to form a single national GIS shapefile.

[12] Jackson (1980) notes that FHA underwriters were instructed to account for 8 criteria, with "relative economic stability" and "protection from adverse influences"—widely understood to refer to racial minorities and non-WASP whites—collectively accounting for 60% of neighborhood scores (435).

quality, which may be predictive of both ongoing neighborhood trends.[13] The ratings therefore are a useful for reducing the dimensionality of factors leading to to later slum clearance programs, urban renewal, and highway placement. As the summary tables at the bottom of Figure 1 demonstrate, low-rated (C and D) tracts were not only more prevalent within urban areas, but were also much more likely to be subjected to placement of an Interstate highway. Depending on how one defines placement of an Interstate through a neighborhood (either treating Interstates as a line or defining their impact area as a 400-meter buffer zone), HOLC-tracts given a D rating were around three times as likely to be subjected to Interstate highway construction as A-rated neighborhoods. Our use of HOLC grades follows on prior uses of natural propensity score equivalents, including home values (Keele and Titiunik 2016) and estimated ideal points (Lupu 2013) used as balancing scores (Rosenbaum and Rubin 1983). However, we do not rely exclusively on these scores.[14] In our matching and regression analysis, we subclassify (exact-match) on HOLC rating, then perform additional matching within each HOLC grade.

Because the HOLC rating captures only some of the factors used to select neighborhoods for highway construction. We also assembled, and matched and regressed on, additional historical covariate data on the physical, social, and economic factors contributing to state highway departments' decision to build Interstate highways in a neighborhood (Rubin 1991).

We also accounted for physical factors, including natural features and preexisting infrastructure, that determined Interstate highway construction locations. Previous studies on highways' economic effects have used previously built infrastructure such as rail lines as an instrument predicting subsequent placement of highways and other infrastructure. Duranton and Turner (2012), for example, used an 1898 railroad map as an instrument for highways built by 1983, as railroads and highway departments built roads on similar land. The previous construction of rail lines through a community may have increased, or at least predicted, a residential neighborhood's prob-

[13] Hillier (2003), for example, suggests that HOLC maps were not directly used by private lenders, and instead summarized extant financial practices.

[14] While Rosenbaum and Rubin (1983) demonstrate that the *true* propensity score operates as a balancing score, scholars typically use crudely estimated propensity scores in propensity score matching. The assumptions needed for such matching to work are rarely satisfied, but such methods can reduce imbalance between treated and control units.

ability of placement of an Interstate highway in a neighborhood. However, railroad infrastructure also led to localized industrial development and 19th century urbanization in metropolitan areas (Atack et al. 2010; Baum-Snow et al. 2012; Rodden 2014). Rail lines, often regarded as a physical nuisance, tend to be located in river valleys and run through and along industrial zones, and they provide a single continuous right of way. As a result, they tend to be adjacent to, and sometimes delineate, "slum" areas that may be most exposed or vulnerable to highway construction (Ananat and Washington 2009).[15]

Rather than pursuing an instrumental variables approach, we included historical railroads as a covariate in matching and regression. Using the full historical railroad, river and canal databases assembled by Atack (2016), we created a binary indicator of whether the HOLC-tract had *any railroad mileage within 800m* between 1826 and 1911 (the time coverage of Atack's database). Such HOLC-tracts were twice as likely to become the future site of an Interstate highway as those with no historical railroads. We constructed a similar binary variable indicating whether a *steamboat-navigable river or canal was within 800m* of the HOLC-tract. Both variables are consistent with the suggestion in *Interregional Highways* identified to establish rights of way along waterways. Finally, using our Rand McNally Road Atlas data from 1934 to 1950, we include as an indicator variable whether any *US and state highways that would later become US-numbered highways or Interstates* preexisted in the location, as Interstate expressways were often built alongside or as an upgrade to such roads.[16]

In addition to the HOLC ratings and physical information, we included as controls covariate data from the 1950 US Census, the earliest year for which Census data were broadly available

[15]While we might have used railroads as an instrumental variable for highway placement, we abstained from doing so for three reasons. First, we retained substantive interest in social and political inequalities in highway building, which was inconsistent with estimation of the local average treatment effect (LATE) through instrumental variables analysis. Second, the exclusion restriction is unlikely to be satisfied, as railroads were likely to affect future outcomes by multiple causal pathways other than the construction of Interstate highways. Third, we were concerned with the impact of highways on different categories of urban neighborhoods, and meaningful subgroup comparisons would not have been feasible.

[16]Specifically, we include an indicator for whether any US- or state-signed controlled-access, divided expressways crossed the HOLC-tract, and another for whether there were any other US or state highways that would later be US- or Interstate-signed roads. The latter highways were usually simple two-lane limited-access roads that were paved or otherwise improved.

for urban tracts. To the extent practical, we included baseline (lagged) values of our outcome variables. Our covariates included *log persons per square kilometer in 1950*; *log housing units per square kilometer in 1950*; *non-white proportion of the 1950 population*; and *proportion of occupied housing units that were rented in 1950*.

Causal Identification

To estimate the average effect of highways' placement in urban neighborhoods, we employed exact matching (subclassification) and entropy balancing followed by least squares regression. We first subclassified our samples on HOLC grade, then employed entropy-balancing on the subclassified samples (Hainmueller 2012) as a method of pre-processing to reduce model dependence (Ho et al. 2007) within each HOLC-grade group. We then applied regression models to the resulting weighted data to estimate Interstate highways' effect in treated areas with the same HOLC ratings, and across all matched units. Separately, we estimated the same regression models to the unweighted subclassified data. Because key baseline differences across neighborhoods were captured by HOLC ratings, we subclassified HOLC-tracts accordingly, placing them into three categories: A/B, C, and D. Ratings of A and B usually identify neighborhoods considered most desirable, and they were sufficiently rare that the two categories were combined. C and D ratings were given out much more often, and were meant to distinguish between neighborhoods considered merely risky and those considered the most hazardous for lenders and insurers.

Within each of the three HOLC rating categories, we conducted least squares regression results with and without matching to estimate the average effect of highway development. For each Census year t, 1960–2010, and for each of the three HOLC categories $h \in A/B, C, D$, we separately estimated the coefficient on the non-time varying binary treatment variable Z by the following least squares regression:

$$Y_i = \beta_0 + \beta_1 Z_i + \beta_2 H_i + \sum_{j=3}^{k} \beta_k X_{ik} + \epsilon_i \tag{2}$$

In these regressions, Y represents either of the two outcomes of interest (log population or log housing density), and our quantity of interest is β_1, the coefficient on Z, while k indexes the columns of covariate matrix X. When combining data from the three HOLC subclasses, we run the regression on the applied

$$Y_i = \beta_0 + \beta_1 Z_i + \beta_2 H_i + \sum_{j=2}^{k} \beta_k X_{ik} + \epsilon_i \tag{3}$$

Because we defined Z as a non-time-varying treatment, focusing on post-treatment change over time, we separately estimated its effect for two separate treatment cohorts: HOLC-tracts in which and Interstate was built before 1960, and those with Interstates built during the 1960s.

When conducting regressions on our matched (entropy-balanced) samples (Hainmueller 2012), we weighted observations to match the covariate distribution of untreated units to those of treated units within each HOLC subclass. Then, using the weights generated in entropy balancing, we estimated weighted least squares regressions following the same functional form above and using the same set of covariates.

Analysis

Our analyses demonstrate that Interstate highways caused sharp and persistent declines in population and housing stock for decades after they were built, and these declines were in addition to those resulting from neighborhood poverty, racial segregation, white flight, or urban renewal policies. We begin by reporting Interstates' effects on the matched and unmatched samples in the full sample, then report the coefficient estimates from the two sets of regression results, in each of the two treatment cohorts and for each of the three HOLC classes (A/B, C, and D).

Figure 2 presents the results of the least squares analyses on the full sample, conducted with and without the entropy-balancing weights. Interstates built before 1960 reduced population and housing unit stock in affected areas by approximately 10 percent on average, corresponding to about 200 housing units and 400 persons per square kilometer. Interstate segments built in the following decade had larger negative effects, resulting in upwards of a 20 percent drop in housing stock and about a 15 percent drop in population as of 2000.

Figures 3 and 4 present the percentage change results for housing and population, respectively, by HOLC-grade. While C- and D-rated neighborhoods were more likely to suffer placement of Interstate highways, once such highways were built the relative population and housing losses were not substantially larger than those experienced in other affected neighborhoods. Figure 3 shows that Interstates caused the housing supply in D-rated neighborhoods to drop by about 15 to 20 percent, a slightly larger effect than in A- and B-rated neighborhoods, and nearly twice the negative effect in C-rated neighborhoods. These negative effects appeared in both construction period cohorts, and persisted for decades(though effects decayed slightly by the 2000 and 2010 Censuses. Interstates' effect on population by density in different HOLC grades is similar, as shown in Figure 4. For the most part, the percentage effect on population tracks the loss in housing units.

For HOLC-tracts subjected to highways in the two treatment cohorts, we estimated the aggregate impact of highway construction on their housing and population loss over our study period, reporting highways' overall impact relative to the secular decline already underway in urban neighborhoods. In Figure 5, we report these modeled aggregate values for each decade starting in 1960 and ending in 2010. The figure shows the population and housing losses that would have been expected absent Interstate highway construction (the "counterfactual"), and the estimated aggregated population and housing loss resulting from highways. The gray lines indicate the expected levels of housing and population over time, had no Interstate been built, while the differences represent our estimate of Interstates' effects. Affected HOLC-tracts would have had 1.3 million housing units in 1960 and a population of approximately 3.6 million persons. By 1990—the year at which Interstate highways' adverse effects appear to have peaked—these HOLC-tracts would have expected to experience a housing stock decline of over 100,000 units and a population decline of about 675,000 persons in the absence of Interstates. Because of Interstates, these neighborhoods suffered an additional loss of approximately 200,000 housing units, and about 375,000 persons.

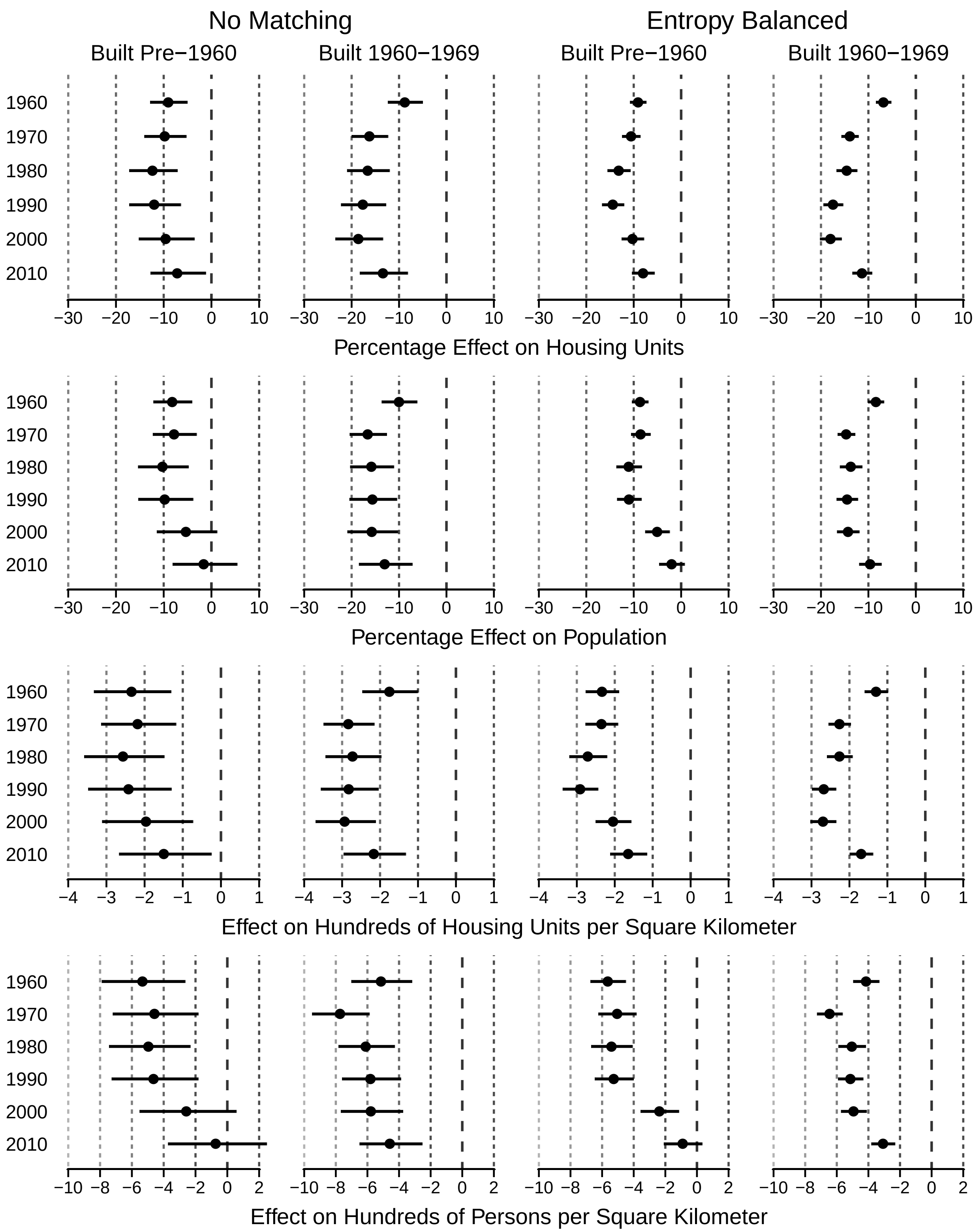


Figure 2: Effect on housing-unit and population density from placement of a highway through a HOLC-tract, for Interstate highways built pre-1960 and 1960–1969. Based on decennial Census data on tract-level housing units (Fitch and Ruggles 2003; Manson et al. 2017). Horizontal segments are 95% confidence intervals.

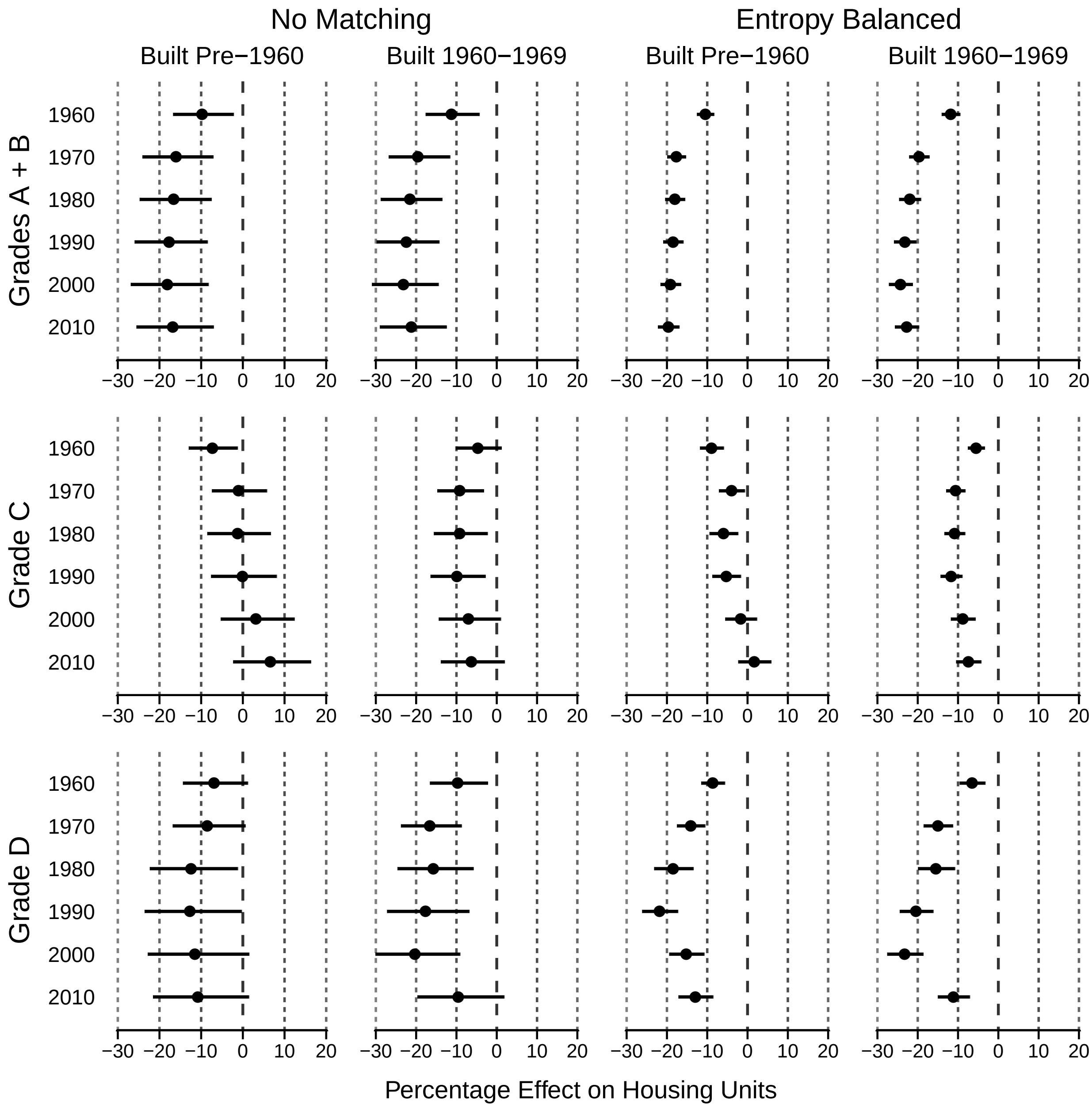


Figure 3: Effect on housing-unit from placement of a highway through a HOLC-tract, for Interstate highways built pre-1960 and 1960–1969, by HOLC grade. Based on decennial Census data on tract-level housing units (Fitch and Ruggles 2003; Manson et al. 2017). Horizontal lines are 95% confidence intervals.

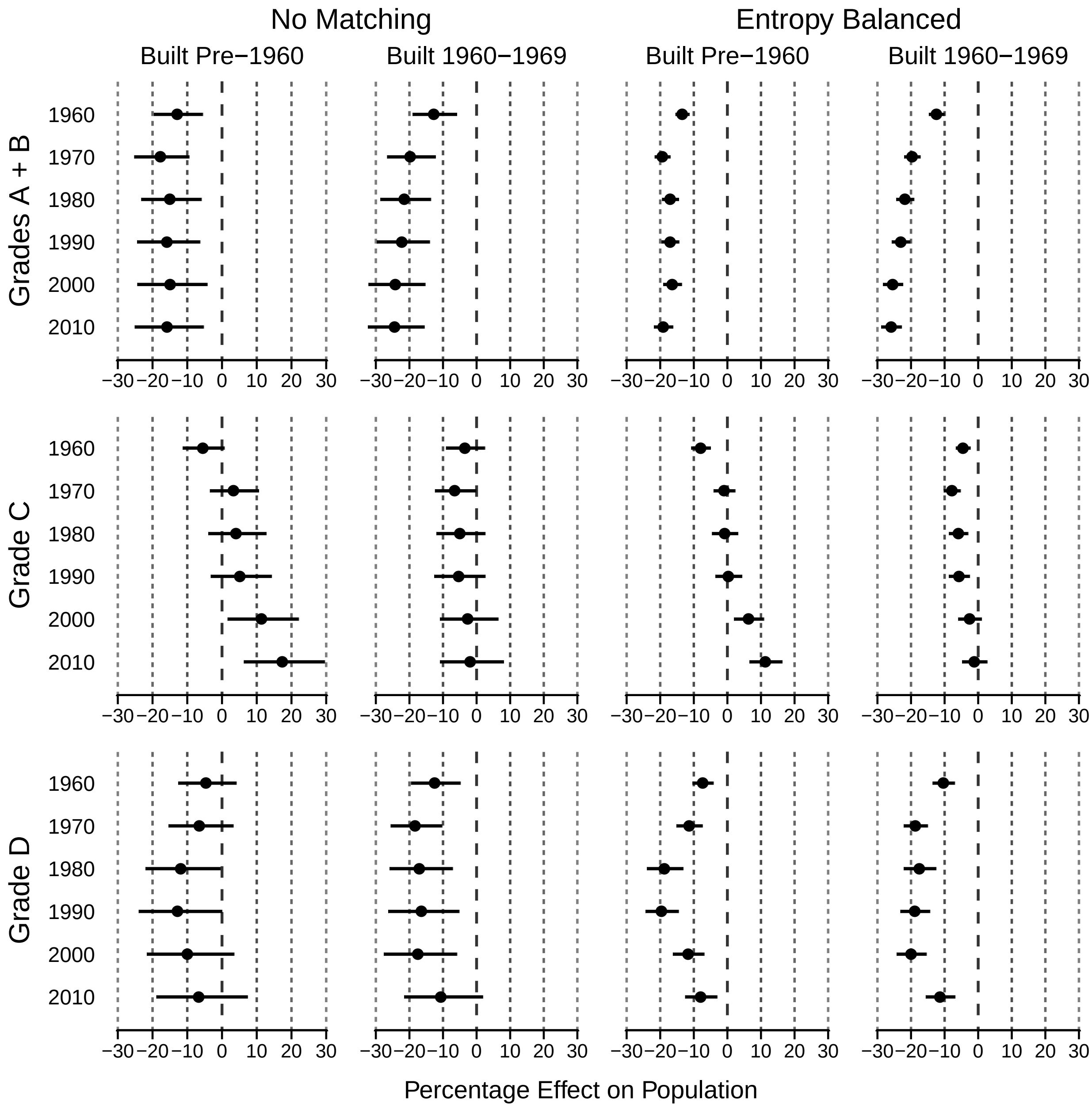


Figure 4: Effect on population from placement of a highway through a HOLC-tract, for Interstate highways built pre-1960 and 1960–1969, by HOLC grade. Based on decennial Census data on tract-level housing units (Fitch and Ruggles 2003; Manson et al. 2017). Horizontal lines are 95% confidence intervals.

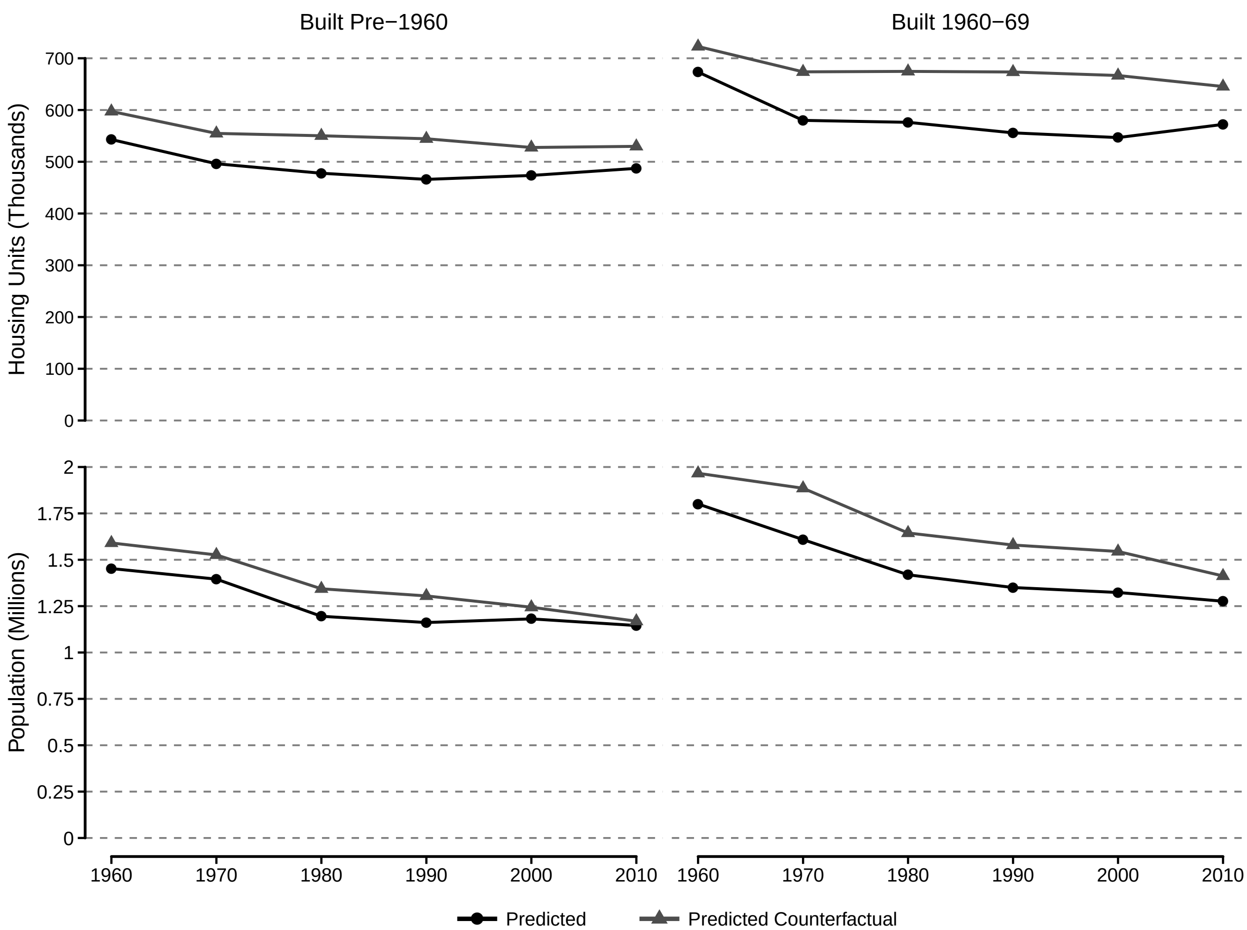


Figure 5: Predicted total housing units and population in HOLC-tracts with Interstate highways built pre-1960 and 1960–1969. Predicted values are reported under treatment (as observed) and for the counterfactual (switching the treatment indicator to zero).

Put differently, at their point of greatest negative impact, Interstates doubled the housing losses that would have otherwise been expected, and increased population losses by 50 percent.

The aggregate effects of highway construction by HOLC grade were, as expected, quite different.While Figures 3 and 4 suggest there were negligible differences in the effects highways had on housing and population between A- and B-rated neighborhoods compared to D-rated neighborhoods–so that the highest-rated neighborhoods may have even suffered *more* than C-rated ones—Figure 6 reveals the extent to which low-SES neighborhoods disproportionately suffered as a result of highway policy. Because C- and D-rated neighborhoods were disproportionately chosen as Interstate locations, they accounted for most much of the population loss.

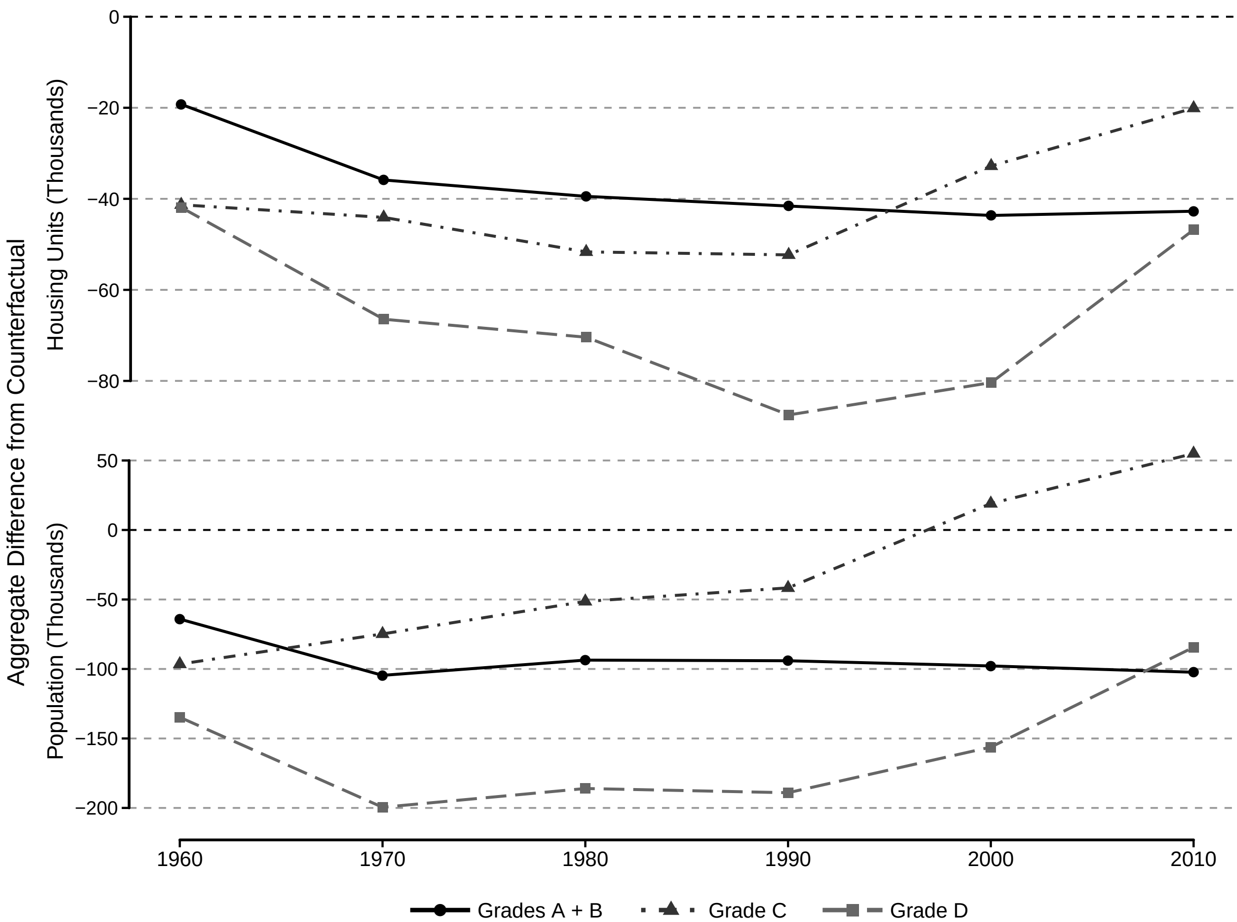


Figure 6: Total predicted difference in housing units and population in HOLC-tracts with Interstate highways built pre-1960 and 1960–1969 compared to the predicted counterfactual, by HOLC grade. Predicted differences are generated by subtracting counterfactual values (predicted values when the treatment indicator is zero) from predicted values.

Following the logic in Figure 5, Figure 6 plots the aggregate difference in housing and population density compared to the predicted counterfactual. Negative values indicate that, controlling for any trends unrelated to highways that might affect housing or population, the construction of an Interstate caused an additional loss. The predictions used to generate these figure are taken from the subgroup analyses. These differences are then summed over all affected units for both treatment cohorts (i.e., those in which a highway was built before 1960, as well as those that received an Interstate between 1960 and 1969), and plotted by HOLC grade.

Two key findings arise from this analysis. First, while the percentage effect of highways on housing in C-graded neighborhoods was lower than for A- and B-graded neighborhoods, the aggregate losses were still greater through 1990. Combining this with the fact that the effect on population is comparatively lower for every decade except 1950 (and in fact *increased* by 2000) suggests the placement of highways through these neighborhoods may have contributed to crowding. Second, and more importantly, before 2010 the D-rated neighborhoods accounted for a larger share of aggregate population and housing loss than A- and B-rated neighborhoods. Figure 6 shows that, for most of the time period under investigation, areas that were coded as most "hazardous" by assessors suffered *twice* the population and housing losses that occurred in the most desirable neighborhoods. At the peak of the effect in 1990, highways caused D-rated neighborhoods to lose about 87,000 housing units, while A- and B-rated neighborhoods lost just 41,000. Highways caused C-rated neighborhoods to lose an additional 52,000. The aggregate effect also indicates that average population density losses concealed overall recovery across lower-ranked neighborhoods. C-rated neighborhoods, in particular (which tended to be white working class neighborhoods with older housing stock) had modest aggregate losses initially, and highways caused such places to gain net population by 2010.

The net loss of housing stock provides only one measure of how the Interstate highway program affected neighborhoods. Even if housing stock in neighborhoods declined, such neighborhoods might have retained population if residents had crowded into remaining housing units. This commonly occurred in the wake of slum clearance programs (Hirsch 2009). In additional results reported in the Online Appendix (p. 23), we show that HOLC-tracts in which state highway departments built Interstates lost population approximately in proportion to their loss of housing units, with nearly the same effects. This indicates that highways displaced residents from affected neighborhoods by destroying their housing, but they were not absorbed into the remaining housing stock within those neighborhoods. Highways may have been initially destructive of housing but did not further ghettoize affected areas by concentrating the poor in the residual portions of affected neighborhoods. A possible alternative explanation for this result is that highways forced people into nearby HOLC-tracts, but additional analyses did not support this hypothesis: we obtained substantively similar results even when we defined the highway treatment using a 400-meter buffer around the highways.

In Figures 7 and 8, we find varied evidence that Interstates had a large initial destructive effect, while slightly impeding production of later housing stock in C- and D-rated neighborhoods. A different development pattern appeared in A- and B-rated HOLC-tracts in which highways were built. Among high-rated neighborhoods, construction of an Interstate before 1960 resulted in additional, post-1970 new housing development that partly offset highway-induced losses in older housing stock. In A- and B HOLC-tracts, construction of highways resulted in initial housing losses, followed by a sharp jump in new residential development in the 2000s.

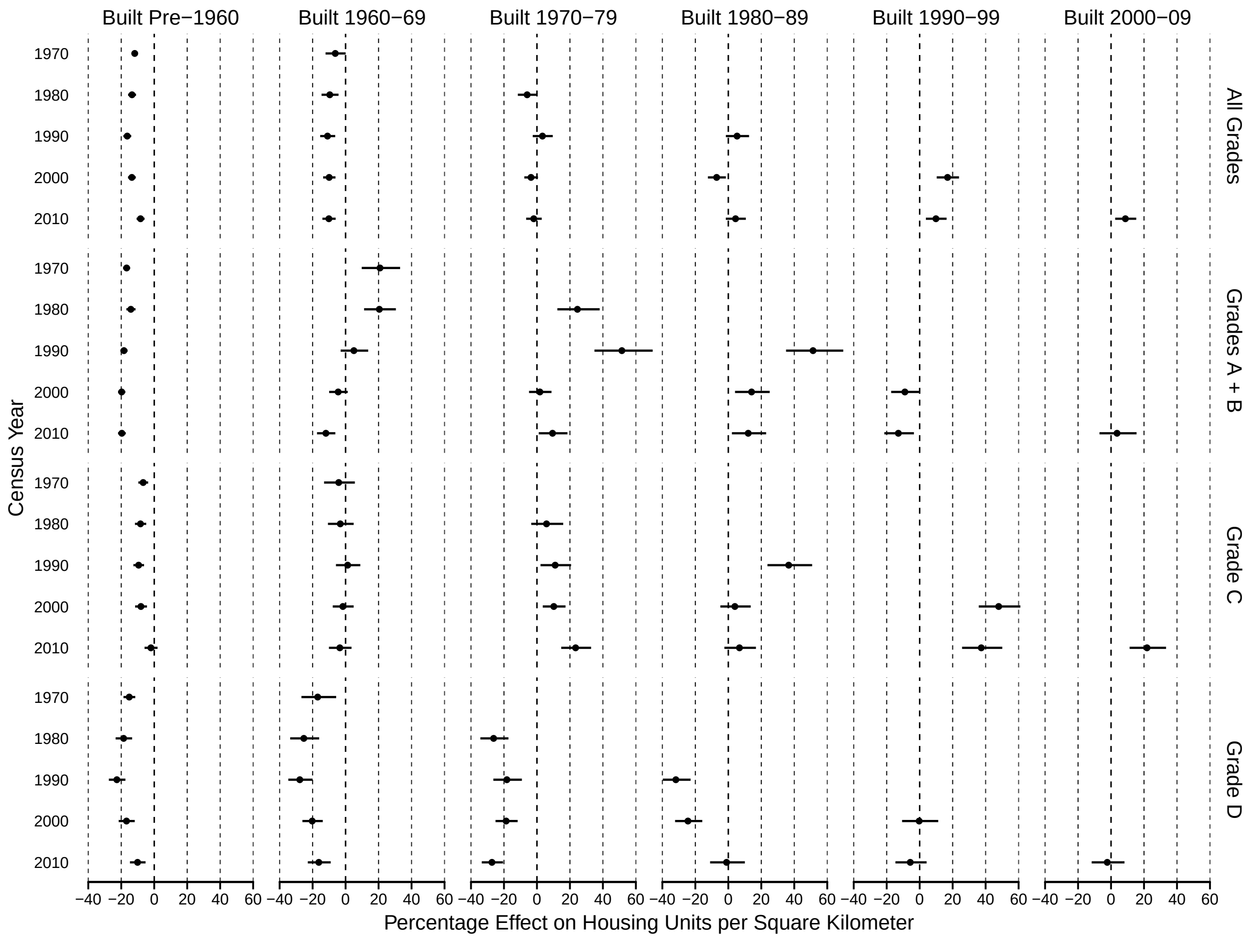


Figure 7: Effect on housing-unit density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960, indicating percentage loss or gain in density of units built in specific decades. Based on decennial Census data on tract-level housing units (Fitch and Ruggles 2003; Manson et al. 2017). Models employ WLS with weights generated from entropy balancing. Horizontal lines are 95% confidence intervals.

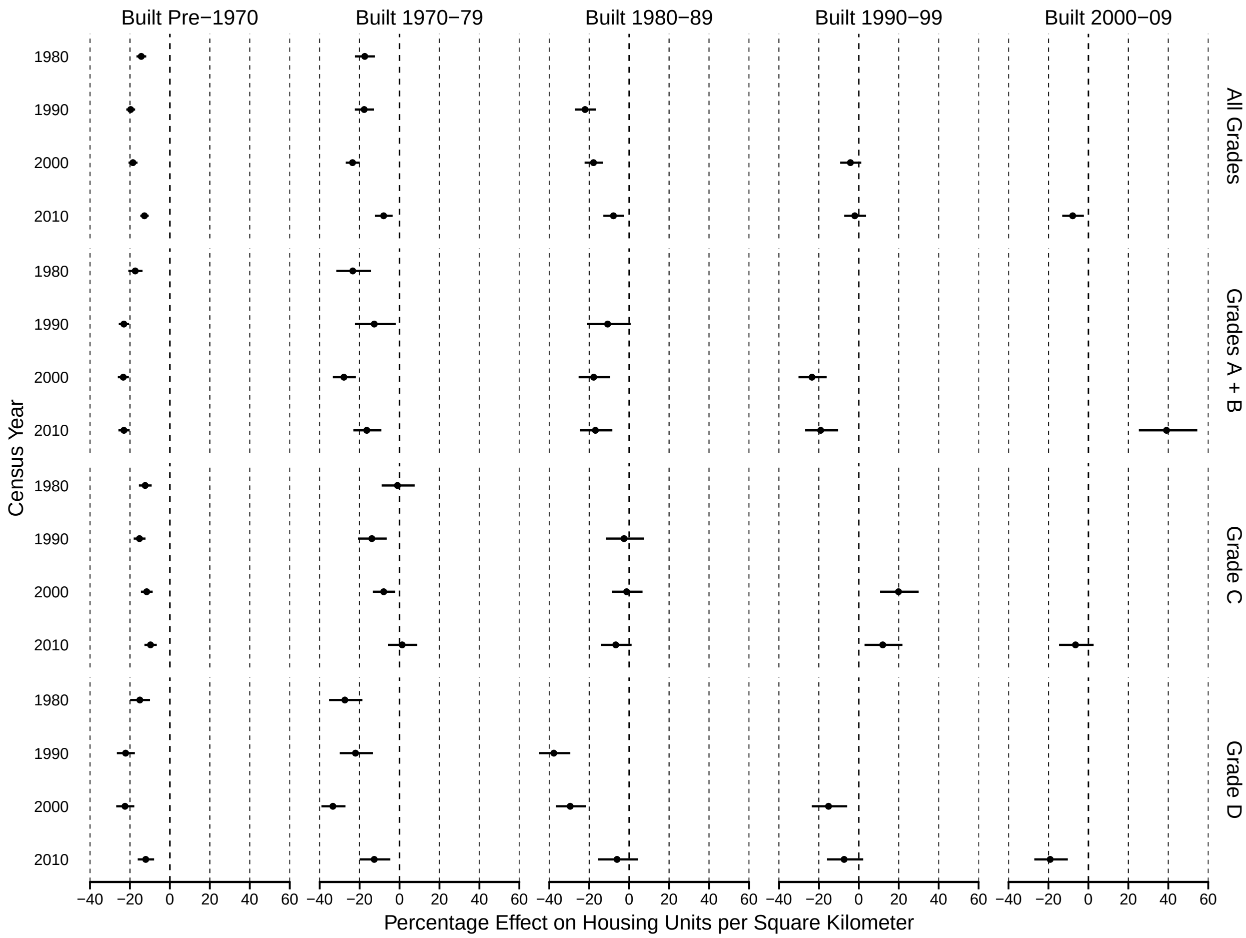


Figure 8: Effect on housing-unit density from placement of a highway through a HOLC-tract, for Interstate highways built between 1960 and 1969, indicating percentage loss or gain in density of units built in specific decades. Based on decennial Census data on tract-level housing units (Fitch and Ruggles 2003; Manson et al. 2017). Models employ WLS with weights generated from entropy balancing. Horizontal lines are 95% confidence intervals.

The coincidence of slum clearance and highway placement may explain the observed drop in housing units and population that preceded construction of highways in the 1960s. This negative placebo effect suggests that our estimates may be biased by unobserved factors. To account for the possibility of omitted variable bias, and to account for the possibility that HOLC-tracts subjected to highway construction were subjected to slum clearance well before construction of Interstates, we reran our regressions accounting for two additional covariates from the 1960 Census: housing unit density and population density. While this model controls for contemporaneous or post-treatment-assignment variables, such covariate adjustment can be appropriate when pre-treatment trends are insufficiently accounted for (Rosenbaum 1984). Accounting for 1960 controls for HOLC-tracts treated in the 1960–1969 cohort reduces the magnitude of post-1960 estimates by approximately 5 to 10 percentage points, with post-Interstate housing unit losses peaking at 15 percent losses in the full sample and 20 percent in D-rated neighborhoods. These results lend strong support to our findings; even after including controls that heavily bias estimates against our hypothesis, Interstates were *still* shown to have large negative effects.

To supplement our results for housing and population stock, which were consistently measured across most of our study period, we estimated Interstates' effects on additional Census variables that were not measured during the pre-treatment period. We are less confident that we were able to account for baseline confounders in such regressions, but we report the results in the Online Appendix (p. 23). One such measure was median home values, which we would have expected Interstates to reduce. However, after entropy balancing, Interstates' effect on median home values was shown to be minimal across neighborhood classes, and, if anything, the effects were positive. We do, however, find that Interstates made affected A, B, and C rated neighborhoods more racially diverse, as measured by the subsequent growth in the nonwhite proportion of the population. And, consistent with Interstates' negative effect on the desirability of areas around Interstates to home buyers, construction of expressways led to a small (2–3 percentage point) increase in the proportion of occupied housing units rented. This adds to the circumstantial evidence that the presence of Interstates may have made such areas less attractive to white home buyers, possibly reinforcing racial segregation.

Conclusion

To what extent did the Interstate highway program function as a method of spatial control over urban neighborhoods? Popular writers, journalists, and historical scholars have documented specific instances of urban elites and planners discussing the use of transportation infrastructure as an instrument of urban renewal. This prior work has typically considered highways' impacts in specific, prominent cases of highway construction, from the Cross-Bronx Expressway to Boston's

Central Artery expressway to the destruction wrought in Miami's Overtown district. Such urban case studies effectively select on a dependent variable—the scale of neighborhood destruction—in a manner that could lead to larger-than-appropriate estimates of highways' average long-term effects in urban neighborhoods.

This study offers, for the first time, an accounting of the national impact of highway construction in major central cities, as well as the impact of Interstate construction in relation to other historical trends in central cities. By our estimation, the Interstate program resulted in the loss—through direct destruction of housing and continuing disinvestment and depopulation—of about 200,000 housing units, and population losses of approximately 375,000 persons in affected HOLC-tracts. These estimates are somewhat smaller in magnitude than past scholars have suggested, owing to the large secular population declines already occurring in neighborhoods where highways were built. While highways were not the sole cause of urban neighborhood decline, the observed long-term population losses were much larger in places where Interstates were built compared to nearly identical places where they had not been built. Our results also provide tentative evidence of the limited duration of highways' adverse effects: while highways' negative effects persisted into the 1990s, by 2010, highway-induced differences had faded substantially.

Our findings reveal the importance of accounting for the counterfactual trajectory of communities when ascribing outcomes to public policy. When scholars and urban observers do not account for these counterfactual differences and trends, they may well conclude that Interstates alone were responsible for all of the long-term adverse effects experienced in the communities in which they were built. Our study shows that the construction of Interstates was a major factor among many contributing to population and housing decline in urban neighborhoods. Communities through which highways were built were additionally subjected to other urban renewal practices, and further impacted by private capital's own redlining practices. Previous claims about Interstates' effects on neighborhoods have not thoroughly compared areas with Interstates to similar areas without them, and, as a result, have not produced unbiased or generalizable estimates of highways as a spatial policy intervention (Rose and Mohl 2012; Karas 2015). When historical comparisons are made appropriately, Interstate highways are seen to be a large, but only partial, contributor to the destruction wrought on poor and racially diverse urban neighborhoods. Our findings bolster previous claims that poor neighborhoods were more likely to be subjected to Interstate construction, and to suffer housing loss and subsequent disinvestment as a result—but only part of their long-term decline can be attributed to the strategic use of infrastructure to clear and redevelop urban neighborhoods.

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Online Appendix

Contents

Summary of the Highway Coding Method

To assemble our historical GIS database of the American highway system, we used the 2013 National Highway Planning Network (NHPN) shapefile of all roads in the United States as a reference (Federal Highway Administration 2013). The map consists of highway line segments containing information on road type, number of lanes, inclusion on the Strategic Highway Network, and other indicators.[17] We selected from this shapefile all roads currently marked as US and Interstate highways, the two types of roads that have consistently been identified over time by AASHO and in commercial atlases as the most important highway routes. We then superimposed the NHPN Interstate/US layer on scans of historical road atlas for the years 1934–1935, 1940, 1950, 1960, 1970, 1980, and 1990.

Using ArcGIS, research assistants manually assigned attributes for road quality and type to each of the segments in the NHPN shapefile according to the symbology of the corresponding road in the Rand McNally Road Atlases. We coded for two factors: the class of road (whether it was a state-signed, US, or Interstate highway), and the quality of the road, as reported in the Rand McNally atlases. This approach therefore depends on Rand McNally's coding scheme for road quality, which varied over time and reflected contemporaneous road-quality standards.[18]

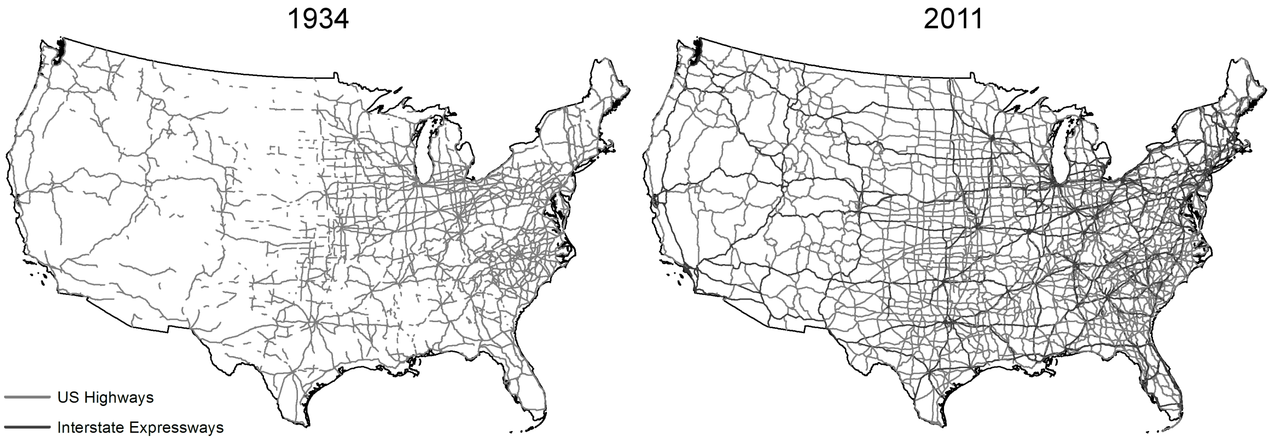
By 1960, after passage of the Federal-Aid Highway Act of 1956 (which established the Interstates) and expansion of the American freeway systems, the Rand McNally Atlases reported the full present-day road hierarchy, including limited-access toll roads (i.e., turnpikes) and limited-access free roads (i.e., freeways). Through 1990, we produced a complete manual coding of these road segments.[19] In addition to using the data from 2000 and 2011, we primarily relied on the road attribute information provided in NHPN data (ESRI 2001; Federal Highway Administration

[17]Documentation accompanying the file indicates that these data, while released in 2013, were up-to-date as of 2011.

[18]In 1934, for example, most American roads had yet to be paved using modern techniques, and many roads were simply "improved" using gravel or other durable non-pavement surfaces.

[19]Road coding occasionally depended on subjective judgments, so each coder's work was checked independently multiple times: once by a separate research assistant and at least once by one of the coauthors.

Figure A-1: Distribution of highways in 1934 and 2011



2013), but checked their accuracy by comparing them against national-level Rand McNally maps. The road-quality indicators used in our data for each year appear in Table A-1.

Table A-1: Summary of road quality indicators used in coding scheme, by year.

Year(s)	Source	Road-Quality Indicators Used
1934-35	Rand McNally Road Atlas	US Highway (Paved) US Highway (Improved) State Highway (Paved) State Highway (Improved)
1940, 1950	Rand McNally Road Atlas	US Highway (Paved, 4+ Lanes) US Highway (Paved, $<$4 Lanes) State Highway (Paved, $<$4 Lanes)
1960, 1970, 1980, 1990	Rand McNally Road Atlas	Interstate Highways US Highways (Divided) US Highways (Two-Lane)
2000	ESRI Database based on 2000 NHPN	Interstate Highways US Highways (Divided) US Highways (Two-Lane)
2011	NHPN Database	Interstate Highways US Highways (Divided) US Highways (Two-Lane)

Main Regression Results for Primary Analyses

https://v2.overleaf.com/project/5b119af09681343ca6e9c4eb

Table A-2: Effect on housing-unit density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960.

		No Matching			Entropy Balanced			
HOLC Grade	Year	Estimate	SE	p	Estimate	SE	p	N
All	1960	-0.095	0.022	<0.001	-0.095	0.010	<0.001	10,995
	1970	-0.103	0.025	<0.001	-0.112	0.011	<0.001	11,016
	1980	-0.132	0.029	<0.001	-0.141	0.014	<0.001	11,022
	1990	-0.128	0.031	<0.001	-0.156	0.014	<0.001	11,022
	2000	-0.101	0.033	0.002	-0.108	0.013	<0.001	11,022
	2010	-0.074	0.032	0.019	-0.084	0.013	<0.001	11,022
A + B	1960	-0.103	0.041	0.012	-0.111	0.012	<0.001	3,016
	1970	-0.175	0.051	<0.001	-0.194	0.014	<0.001	3,030
	1980	-0.181	0.053	<0.001	-0.199	0.015	<0.001	3,030
	1990	-0.195	0.054	<0.001	-0.204	0.016	<0.001	3,030
	2000	-0.200	0.058	<0.001	-0.212	0.016	<0.001	3,030
	2010	-0.184	0.057	0.001	-0.219	0.017	<0.001	3,030
C	1960	-0.076	0.032	0.018	-0.093	0.016	<0.001	4,615
	1970	-0.011	0.034	0.756	-0.040	0.017	0.018	4,625
	1980	-0.012	0.039	0.751	-0.062	0.019	0.001	4,627
	1990	-0.001	0.040	0.985	-0.054	0.019	0.004	4,627
	2000	0.031	0.044	0.476	-0.017	0.020	0.399	4,627
	2010	0.064	0.044	0.152	0.017	0.020	0.415	4,627
D	1960	-0.072	0.043	0.092	-0.090	0.016	<0.001	3,364
	1970	-0.089	0.048	0.066	-0.152	0.021	<0.001	3,361
	1980	-0.133	0.061	0.031	-0.204	0.030	<0.001	3,365
	1990	-0.136	0.068	0.045	-0.246	0.029	<0.001	3,365
	2000	-0.122	0.070	0.080	-0.165	0.026	<0.001	3,365
	2010	-0.114	0.066	0.081	-0.139	0.025	<0.001	3,365

Table A-3: Effect on housing-unit density from placement of a highway through a HOLC-tract, for Interstate highways built between 1960 and 1969.

		No Matching			Entropy Balanced			
HOLC Grade	Year	Estimate	SE	p	Estimate	SE	p	N
All	1960	-0.092	0.020	<0.001	-0.071	0.009	<0.001	11,126
	1970	-0.177	0.023	<0.001	-0.150	0.011	<0.001	11,144
	1980	-0.182	0.027	<0.001	-0.158	0.013	<0.001	11,149
	1990	-0.194	0.029	<0.001	-0.192	0.013	<0.001	11,149
	2000	-0.206	0.031	<0.001	-0.198	0.014	<0.001	11,149
	2010	-0.144	0.030	<0.001	-0.120	0.012	<0.001	11,149
A + B	1960	-0.119	0.038	0.002	-0.126	0.013	<0.001	3,019
	1970	-0.218	0.048	<0.001	-0.219	0.016	<0.001	3,032
	1980	-0.243	0.049	<0.001	-0.248	0.018	<0.001	3,032
	1990	-0.254	0.051	<0.001	-0.264	0.018	<0.001	3,032
	2000	-0.263	0.055	<0.001	-0.278	0.020	<0.001	3,032
	2010	-0.238	0.053	<0.001	-0.258	0.020	<0.001	3,032
C	1960	-0.048	0.030	0.114	-0.057	0.011	<0.001	4,639
	1970	-0.096	0.032	0.003	-0.112	0.013	<0.001	4,647
	1980	-0.096	0.037	0.010	-0.115	0.015	<0.001	4,648
	1990	-0.104	0.038	0.007	-0.124	0.016	<0.001	4,648
	2000	-0.073	0.042	0.084	-0.092	0.017	<0.001	4,648
	2010	-0.065	0.043	0.130	-0.077	0.017	<0.001	4,648
D	1960	-0.102	0.040	0.012	-0.067	0.017	<0.001	3,468
	1970	-0.182	0.046	<0.001	-0.162	0.022	<0.001	3,465
	1980	-0.171	0.057	0.003	-0.168	0.028	<0.001	3,469
	1990	-0.194	0.063	0.002	-0.228	0.027	<0.001	3,469
	2000	-0.227	0.067	<0.001	-0.265	0.030	<0.001	3,469
	2010	-0.101	0.061	0.097	-0.118	0.023	<0.001	3,469

Table A-4: Effect on population density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960.

		No Matching			Entropy Balanced			
HOLC Grade	Year	Estimate	SE	p	Estimate	SE	p	N
All	1960	-0.086	0.022	<0.001	-0.091	0.010	<0.001	10,995
	1970	-0.081	0.025	0.001	-0.089	0.011	<0.001	11,018
	1980	-0.108	0.030	<0.001	-0.117	0.015	<0.001	11,022
	1990	-0.103	0.032	0.001	-0.116	0.015	<0.001	11,022
	2000	-0.055	0.034	0.106	-0.052	0.014	<0.001	11,022
	2010	-0.016	0.035	0.645	-0.020	0.014	0.148	11,022
A + B	1960	-0.138	0.041	<0.001	-0.144	0.012	<0.001	3,016
	1970	-0.195	0.049	<0.001	-0.215	0.015	<0.001	3,030
	1980	-0.163	0.052	0.002	-0.187	0.015	<0.001	3,030
	1990	-0.173	0.055	0.002	-0.187	0.016	<0.001	3,030
	2000	-0.161	0.060	0.007	-0.179	0.017	<0.001	3,030
	2010	-0.172	0.060	0.004	-0.212	0.018	<0.001	3,030
C	1960	-0.057	0.032	0.080	-0.083	0.016	<0.001	4,615
	1970	0.032	0.035	0.349	-0.010	0.017	0.556	4,626
	1980	0.040	0.041	0.331	-0.008	0.020	0.681	4,627
	1990	0.050	0.042	0.236	0.003	0.020	0.885	4,627
	2000	0.108	0.047	0.021	0.061	0.021	0.004	4,627
	2010	0.160	0.050	0.002	0.107	0.022	<0.001	4,627
D	1960	-0.047	0.045	0.290	-0.076	0.017	<0.001	3,364
	1970	-0.068	0.051	0.183	-0.121	0.022	<0.001	3,362
	1980	-0.127	0.062	0.042	-0.208	0.034	<0.001	3,365
	1990	-0.137	0.070	0.050	-0.218	0.031	<0.001	3,365
	2000	-0.105	0.071	0.139	-0.125	0.027	<0.001	3,365
	2010	-0.069	0.071	0.333	-0.083	0.026	0.002	3,365

Table A-5: Effect on population density from placement of a highway through a HOLC-tract, for Interstate highways built between 1960 and 1969.

		No Matching			Entropy Balanced			
HOLC Grade	Year	Estimate	SE	p	Estimate	SE	p	N
All	1960	-0.105	0.021	<0.001	-0.088	0.009	<0.001	11,126
	1970	-0.182	0.024	<0.001	-0.159	0.011	<0.001	11,147
	1980	-0.172	0.028	<0.001	-0.147	0.014	<0.001	11,149
	1990	-0.170	0.030	<0.001	-0.157	0.013	<0.001	11,149
	2000	-0.171	0.032	<0.001	-0.154	0.014	<0.001	11,149
	2010	-0.140	0.033	<0.001	-0.101	0.013	<0.001	11,149
A + B	1960	-0.136	0.038	<0.001	-0.133	0.013	<0.001	3,019
	1970	-0.220	0.046	<0.001	-0.219	0.015	<0.001	3,032
	1980	-0.242	0.049	<0.001	-0.246	0.017	<0.001	3,032
	1990	-0.252	0.052	<0.001	-0.262	0.018	<0.001	3,032
	2000	-0.277	0.057	<0.001	-0.294	0.020	<0.001	3,032
	2010	-0.280	0.057	<0.001	-0.300	0.021	<0.001	3,032
C	1960	-0.036	0.031	0.243	-0.046	0.012	<0.001	4,639
	1970	-0.067	0.033	0.043	-0.081	0.014	<0.001	4,648
	1980	-0.051	0.039	0.189	-0.061	0.015	<0.001	4,648
	1990	-0.055	0.041	0.181	-0.059	0.017	<0.001	4,648
	2000	-0.027	0.045	0.556	-0.026	0.018	0.157	4,648
	2010	-0.019	0.049	0.697	-0.012	0.019	0.549	4,648
D	1960	-0.133	0.043	0.002	-0.109	0.019	<0.001	3,468
	1970	-0.202	0.048	<0.001	-0.207	0.022	<0.001	3,467
	1980	-0.187	0.058	0.001	-0.193	0.030	<0.001	3,469
	1990	-0.179	0.064	0.005	-0.209	0.028	<0.001	3,469
	2000	-0.192	0.067	0.004	-0.223	0.028	<0.001	3,469
	2010	-0.112	0.067	0.091	-0.121	0.025	<0.001	3,469

Balance Statistics

Table A-6: Unweighted and weighted standardized differences in means for primary variables.

Variable	Treatment Group	HOLC Grade	Standardized Difference	Standardized Difference (Weighted)
ln(Housing Units per Square Kilometer + 1)	Pre-1960	A + B	-0.278	0
	1960-69	A + B	-0.373	0
	Pre-1960	C	-0.359	0
	1960-69	C	-0.456	0
	Pre-1960	D	-0.184	0
	1960-69	D	-0.355	0
ln(Population per Square Kilometer + 1)	Pre-1960	A + B	-0.305	0
	1960-69	A + B	-0.370	0
	Pre-1960	C	-0.325	0
	1960-69	C	-0.460	0
	Pre-1960	D	-0.171	0
	1960-69	D	-0.344	0

Robustness of Results to Buffered Treatment

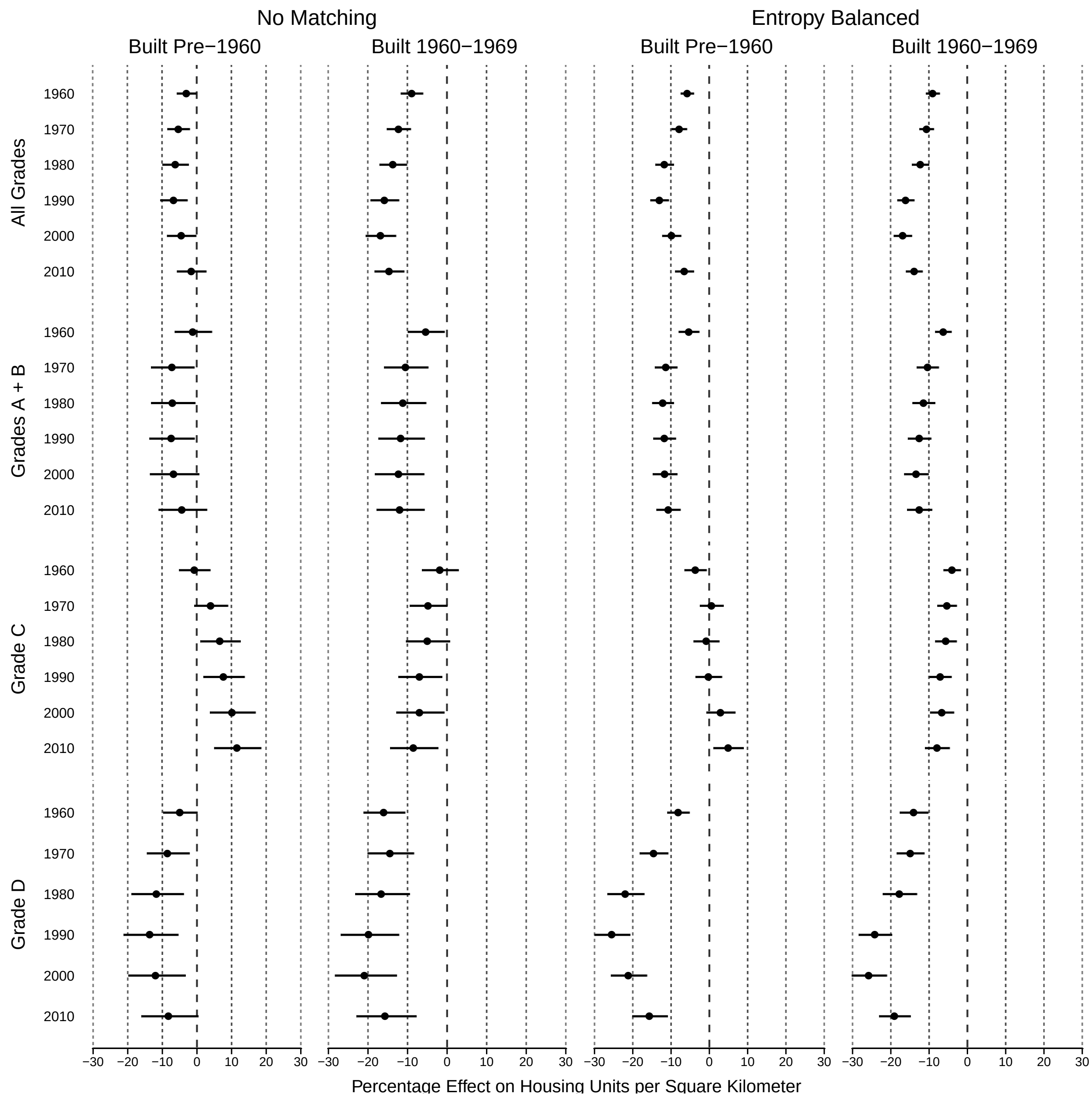


Figure A-2: Effect on housing-unit density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969, with treatment defined by a 400 meter buffer applied to the HOLC-tract. Horizontal lines are 95% confidence intervals.

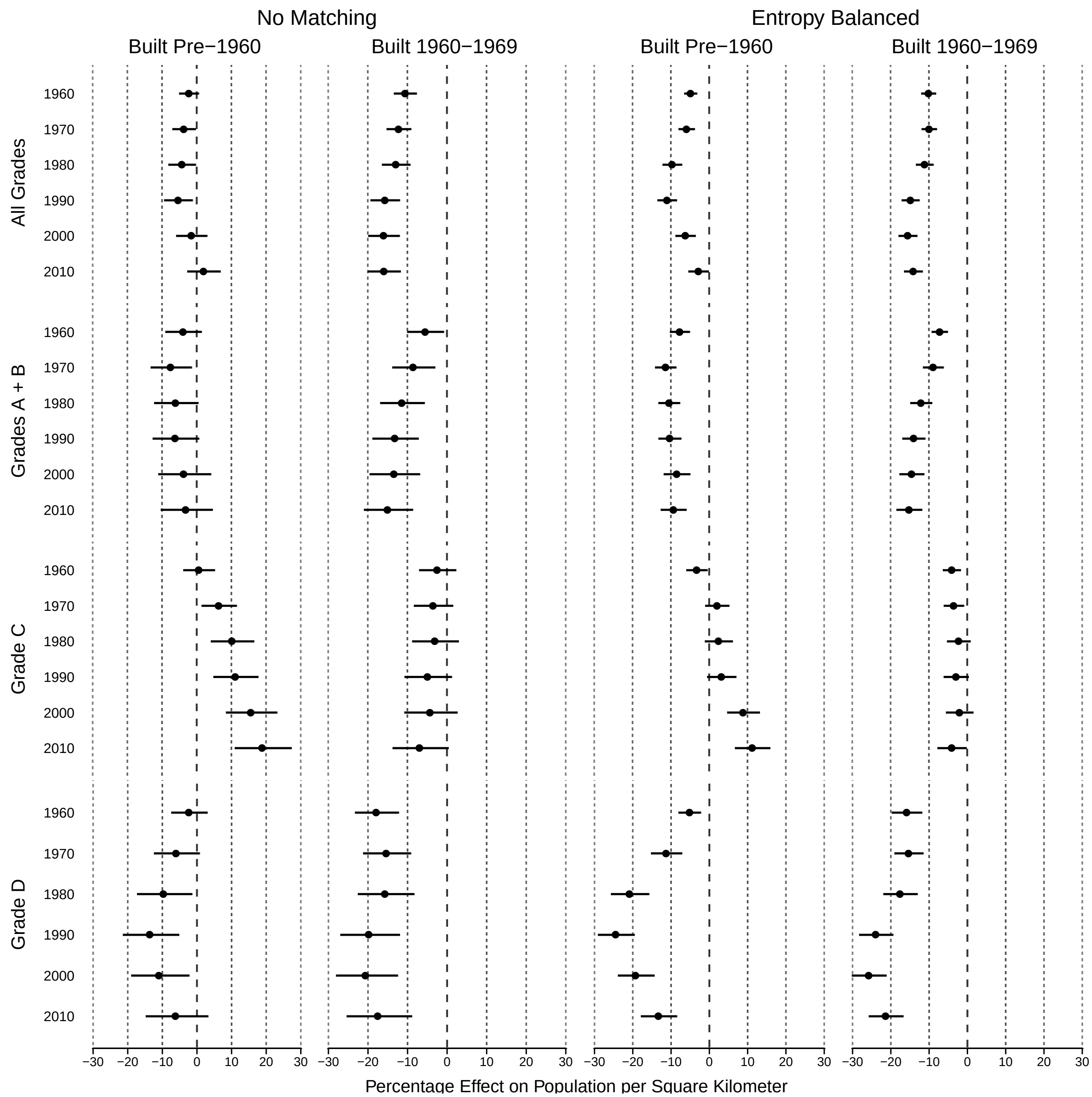


Figure A-3: Effect on population density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969, with treatment defined by a 400 meter buffer applied to the HOLC-tract. Horizontal lines are 95% confidence intervals.

Robustness of Results to Robust Regression

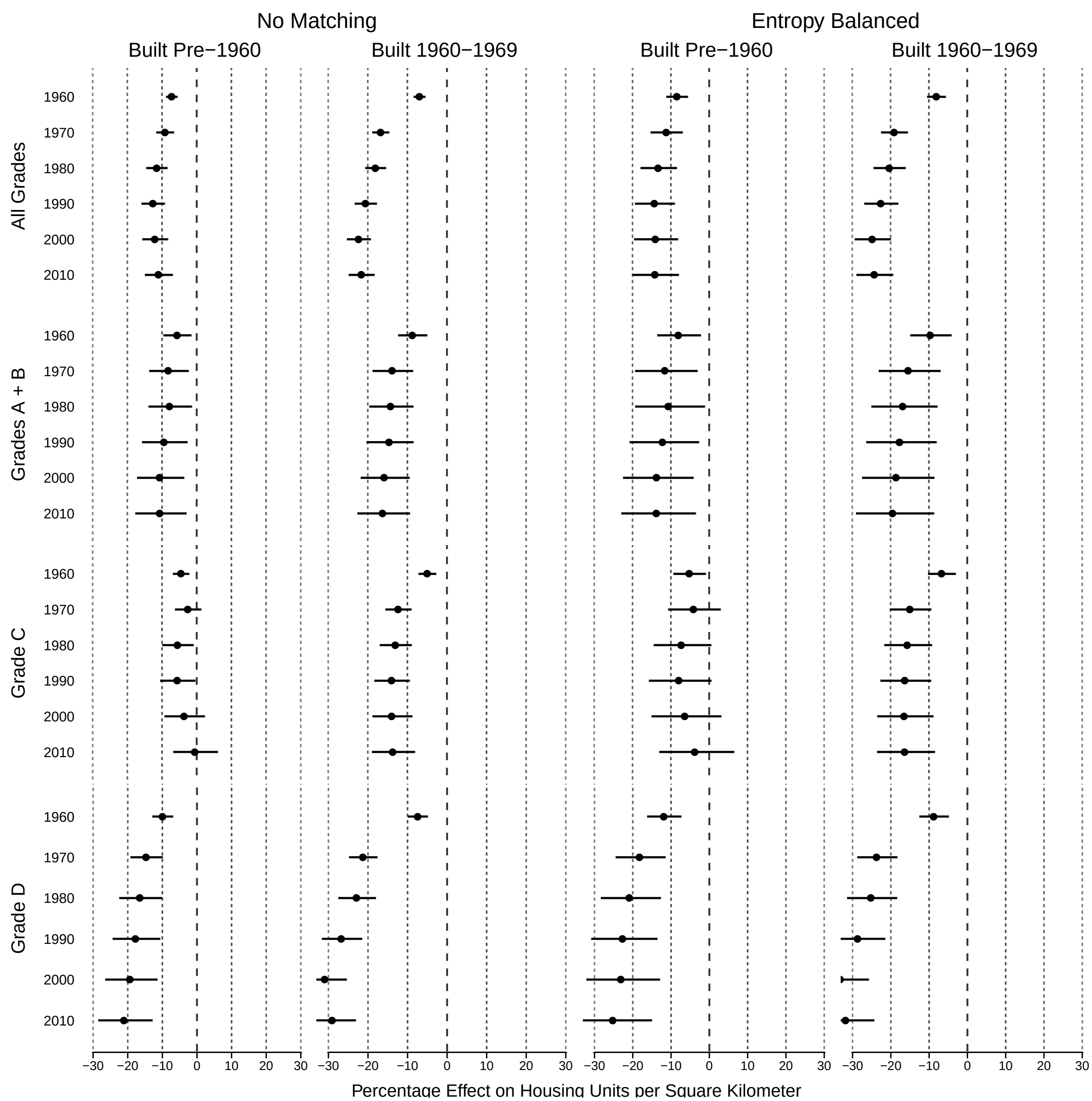


Figure A-4: Effect on housing-unit density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969 (robust regression). Horizontal lines are 95% confidence intervals.

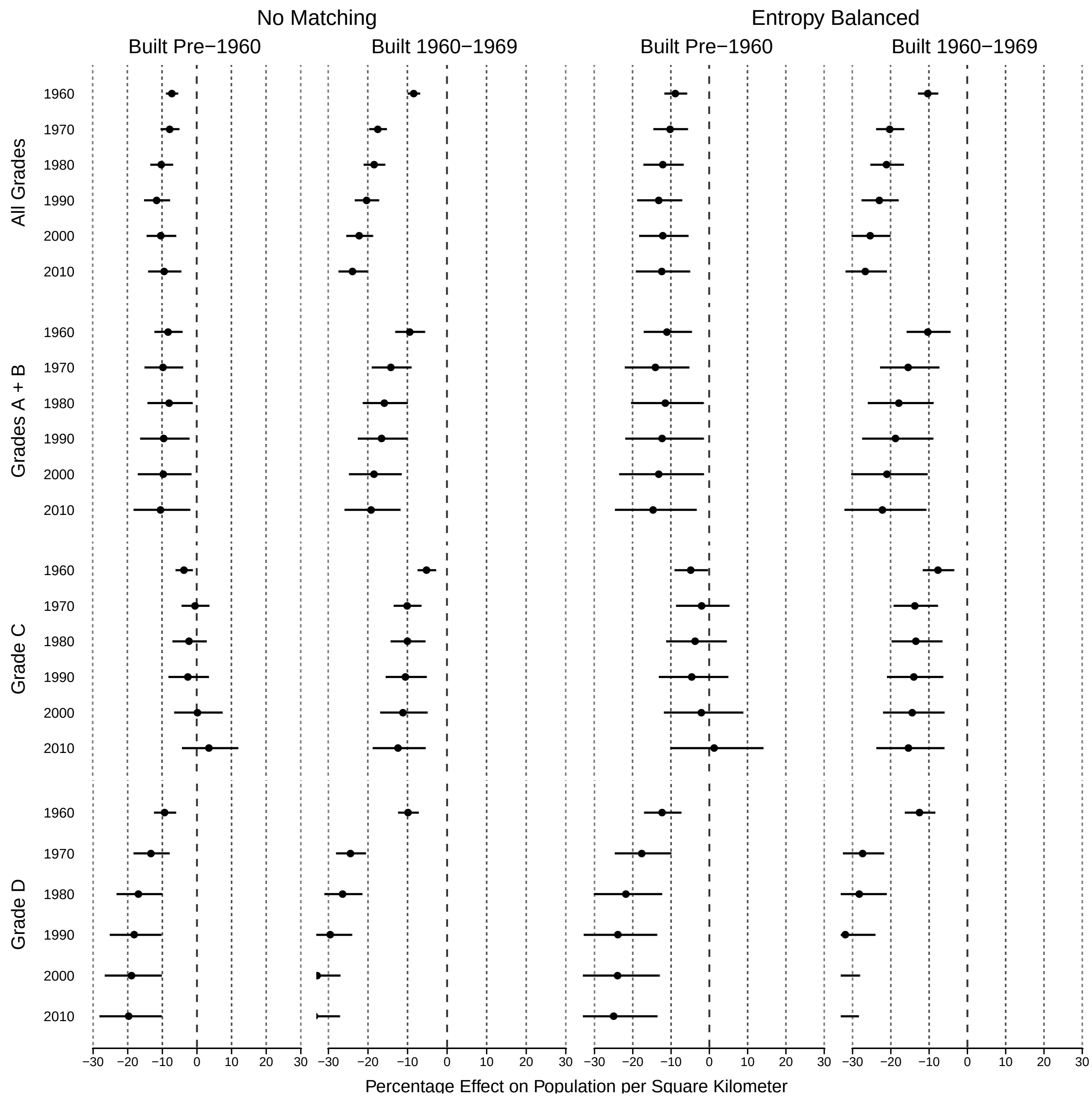


Figure A-5: Effect on population density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969 (robust regression). Horizontal lines are 95% confidence intervals.

Robustness of Results to 1940 Tracts and Covariates

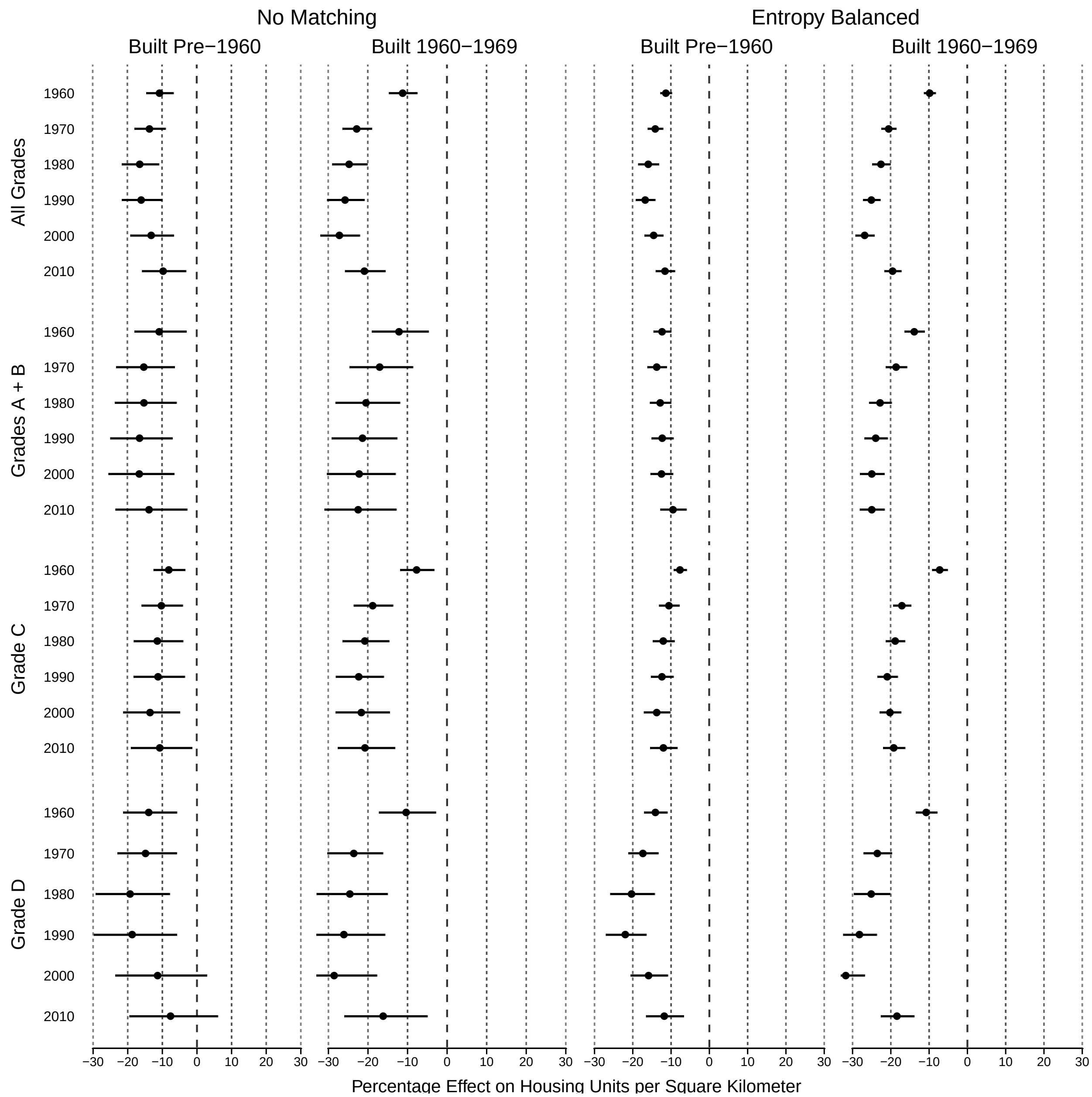


Figure A-6: Effect on housing-unit density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969 (using 1940 tracts and covariates). Horizontal lines are 95% confidence intervals.

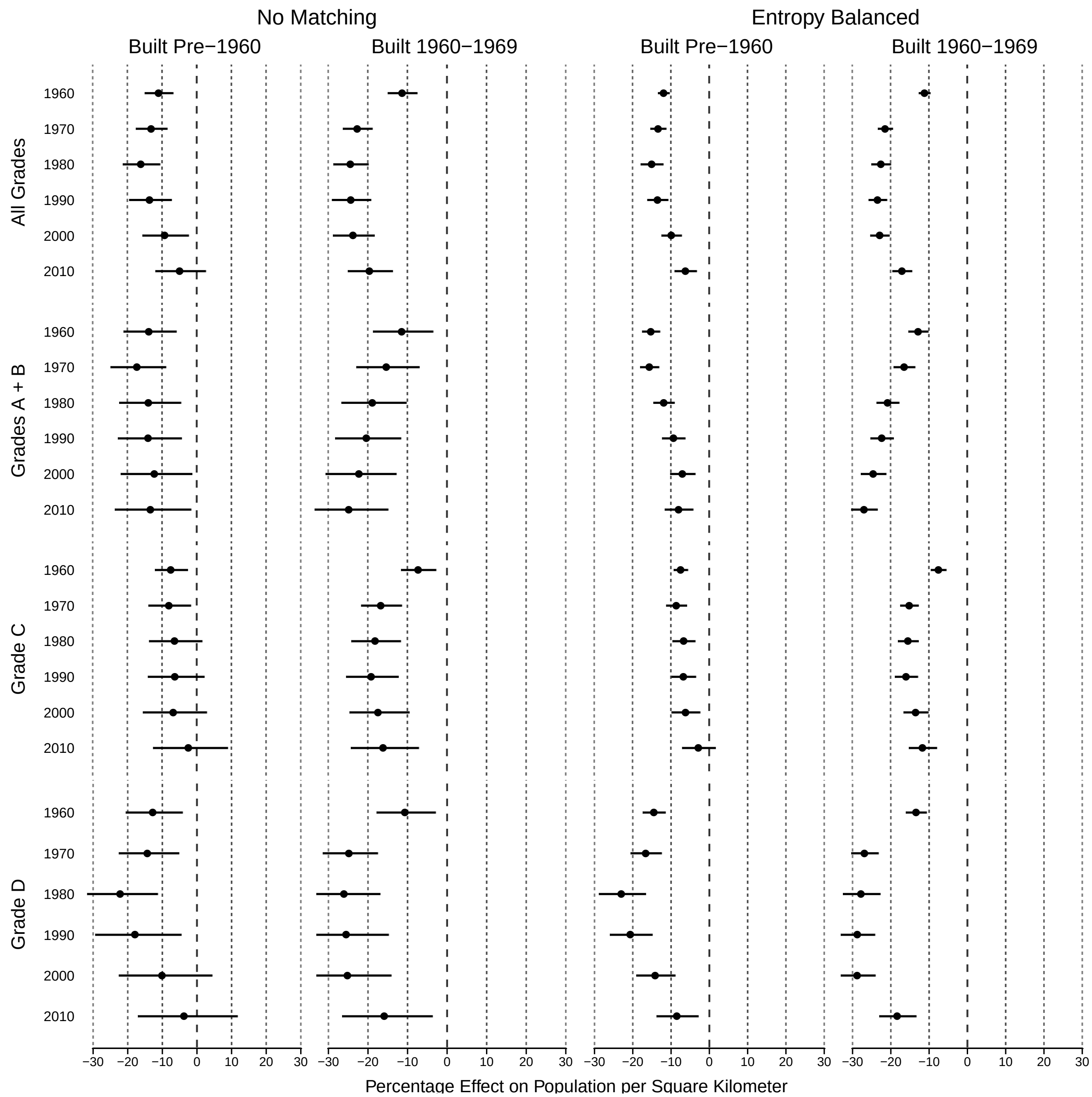


Figure A-7: Effect on population density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969 (1940 tracts and covariates). Horizontal lines are 95% confidence intervals.

Robustness of 1960–1969 Results to 1960 Controls

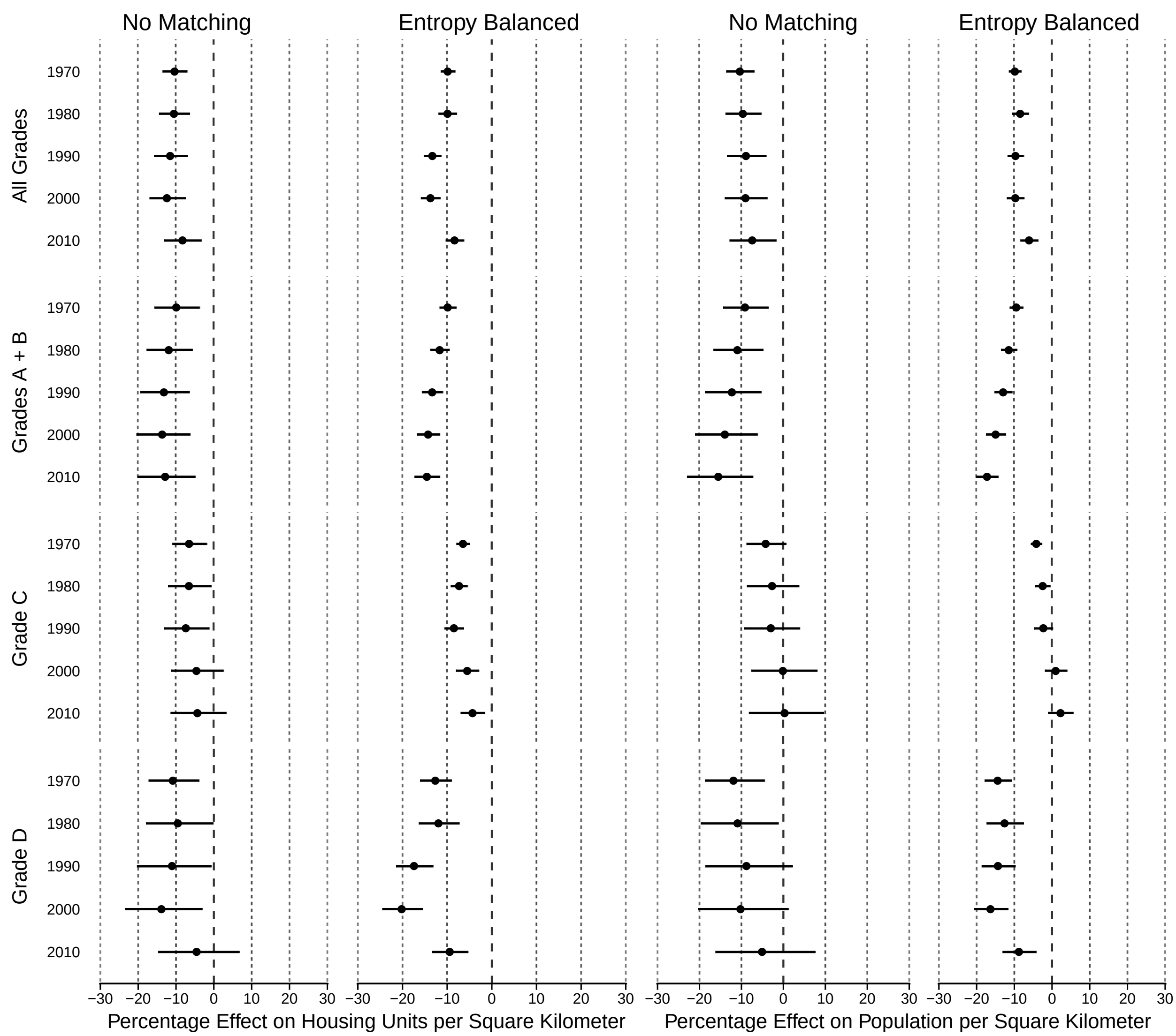


Figure A-8: Effect on housing-unit and population density from placement of a highway through a HOLC-tract, for Interstate highways built between 1960 and 1969 (including 1960 housing unit and population controls). Horizontal lines are 95% confidence intervals.

Robustness of Results to Stricter Areal Interpolation Rules

Because our assumption that Census measures are uniformly distributed over space is unlikely to hold, one might worry that our estimates are biased. While we do not believe the failure of this assumption to hold would bias estimates in favor of our hypotheses (and thus expect the uniformity assumption to simply add noise to our estimates), we attempted to address this by employing stricter rules for exclusion.

In our main results, we drop HOLC-tracts if less than 5 percent of the area of a 1950 Census tract overlaps with a HOLC polygon. Here, we require the following.

1. In every year, intersections between the Census tract and the HOLC-tract are kept only if at least 20 percent of the area of the Census tract overlaps with the HOLC-tract. For 1950, this means that the 5 percent threshold is increased to 20 percent. Referencing Equation 1, this means that $\frac{a_i}{A_i} \geq \frac{1}{5} \forall i$.

2. HOLC-tracts are kept only if at least 75 percent of the HOLC-tract is filled by remaining Census tract intersections in every year. (For 1950, the percentage is always 100, so no additional dropping is done due to 1950 Census tracts.)

3. When calculating interpolated values for population and housing, missing values are not removed. Therefore, if a single part of a HOLC-tract is missing a value, the whole HOLC-tract is coded as missing for that variable in that year (this only affects years after 1950, as they would already be coded as missing in 1950 if the 1950 variable were missing).

Together, points 2 and 3 mean that the sum of proportions are at most multiplied by 4/3. Referencing Equation 1, it means that $\sum_{i=1}^{N} a_i \geq \frac{3}{4} A_h$. These rules drop at least an additional 4,845 HOLC-tracts, about 39% relative to the previous method at baseline. It also drops slightly more depending on the analysis year. However, as shown in Figures A-9 and A-10, results are substantively similar.

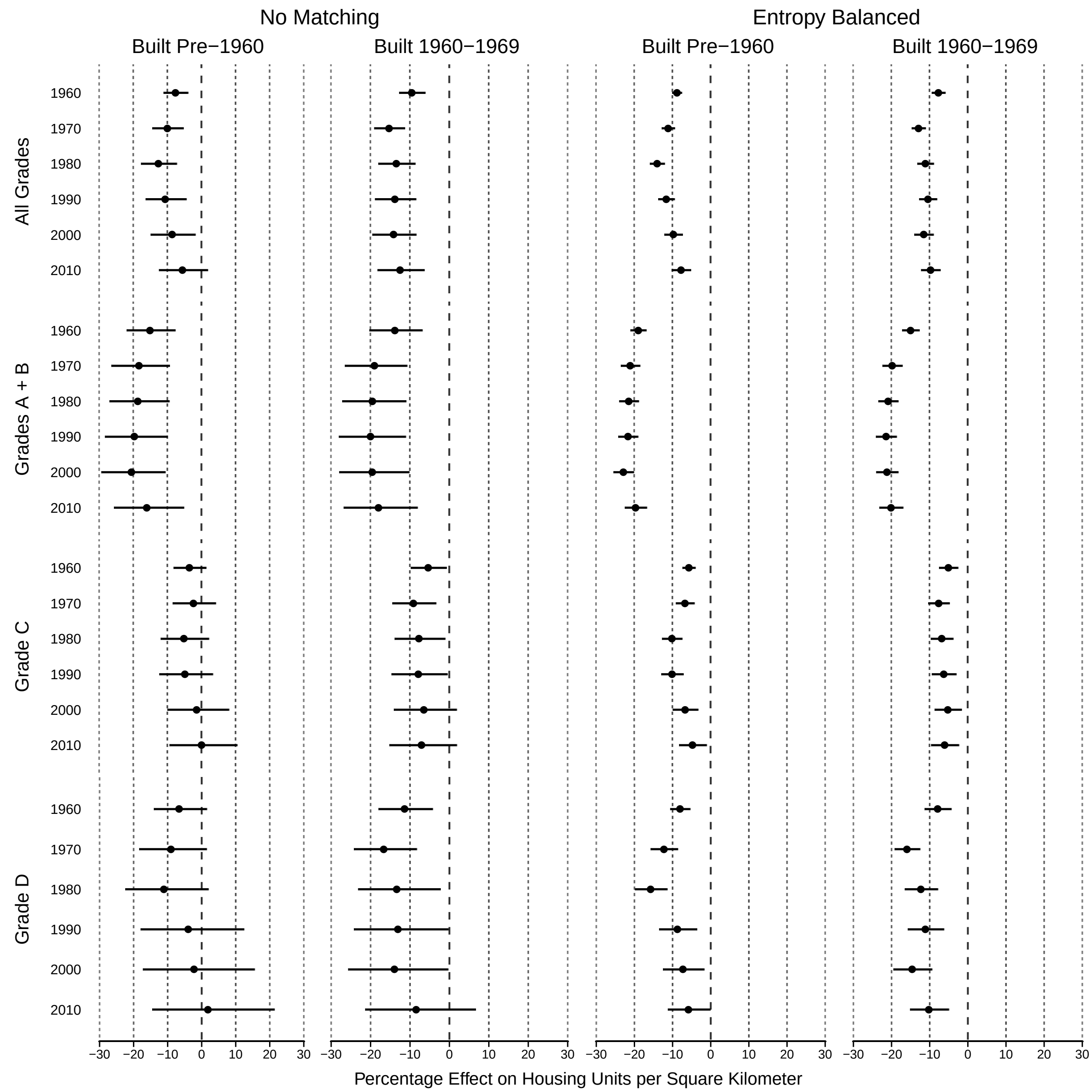


Figure A-9: Effect on housing-unit density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969 (additional areal interpolation restrictions). Horizontal lines are 95% confidence intervals.

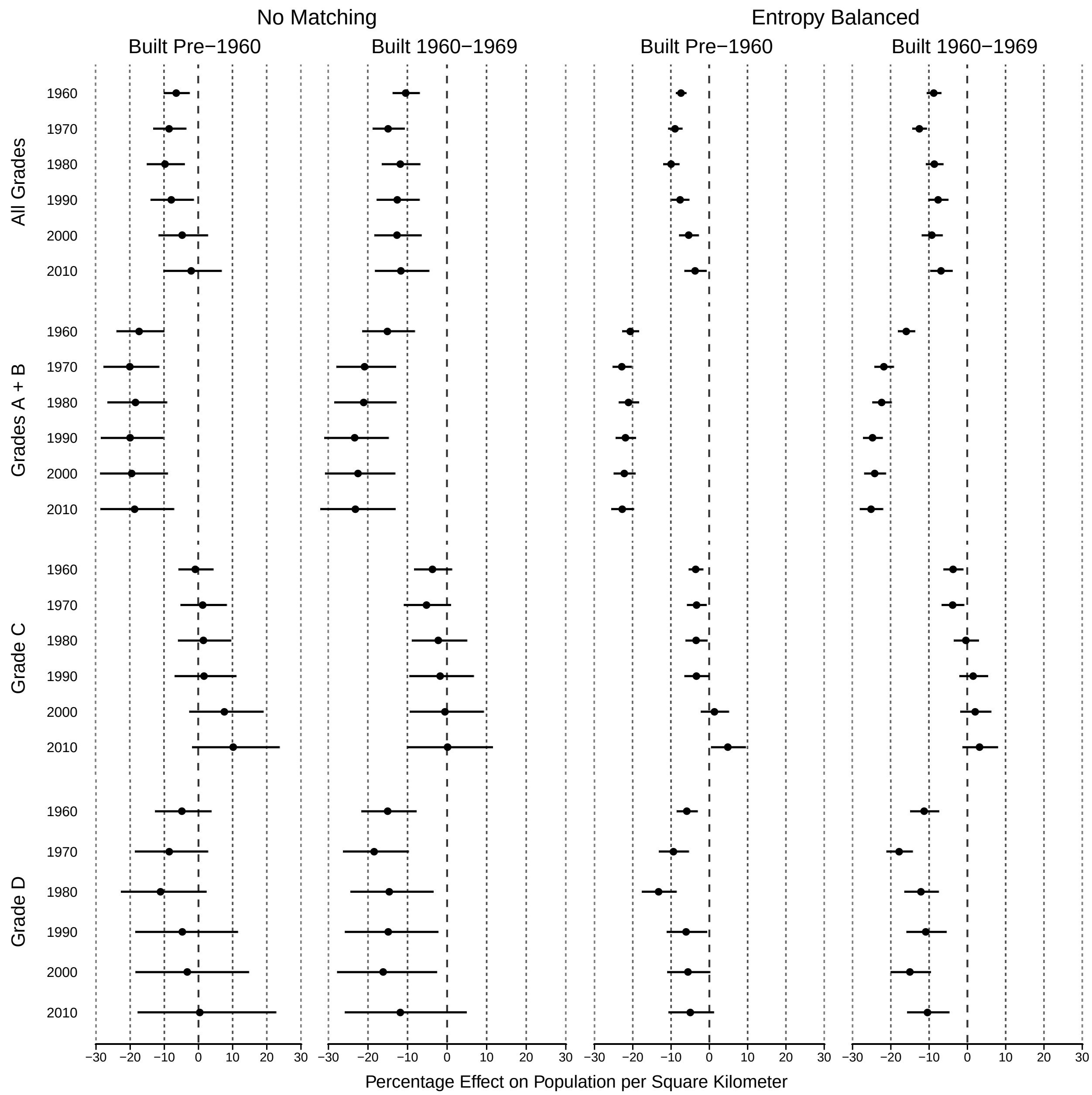


Figure A-10: Effect on population density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969 (additional areal interpolation restrictions). Horizontal lines are 95% confidence intervals.

Robustness of Results to Dropping HOLC-Tracts with Large Decade-on-Decade Fluctuations in Population or Housing

Perhaps the principal concern regarding our assumption of uniform spatial distribution of Census variables is that it might lead to artificially large swings in population or housing. Such inappropriately large fluctuations could potentially bias our estimates. As an additional robustness check, we therefore rerun the regressions by using an alternative dropping rule that is not based on areal overlap, but on observed changes in population and housing. If this approach disproportionately drops HOLC-tracts that truly did experience large negative drops in population and housing units because of highways, it should constitute a conservative test of our hypothesis.

We experimented with a variety of thresholds and obtained similar results. In Figures A-11 and A-12 we report results using the following exclusion criteria. First, we drop all HOLC-tracts that have less than fifty persons or housing units per square kilometer in any year. In such cases with relatively low population and housing density, even small absolute changes could produce relatively large swings from one Census to the next. Second, we calculate the proportion change in housing and population between each adjacent decade from 1950 to 2010, with the lower value of the two as the denominator (i.e., we create proportion change variables for both population and housing for the six decade pairs, where the change is relative to the smaller value, with the floor thus being one). Then, for both population and housing, we drop a HOLC-tract if any of the proportion changes in the six decade pairs is greater than or equal to 2. In other words, if from one decade to the next the population or housing stock was 200 percent or more of the value in one Census compared to the other, the HOLC-tract is dropped.

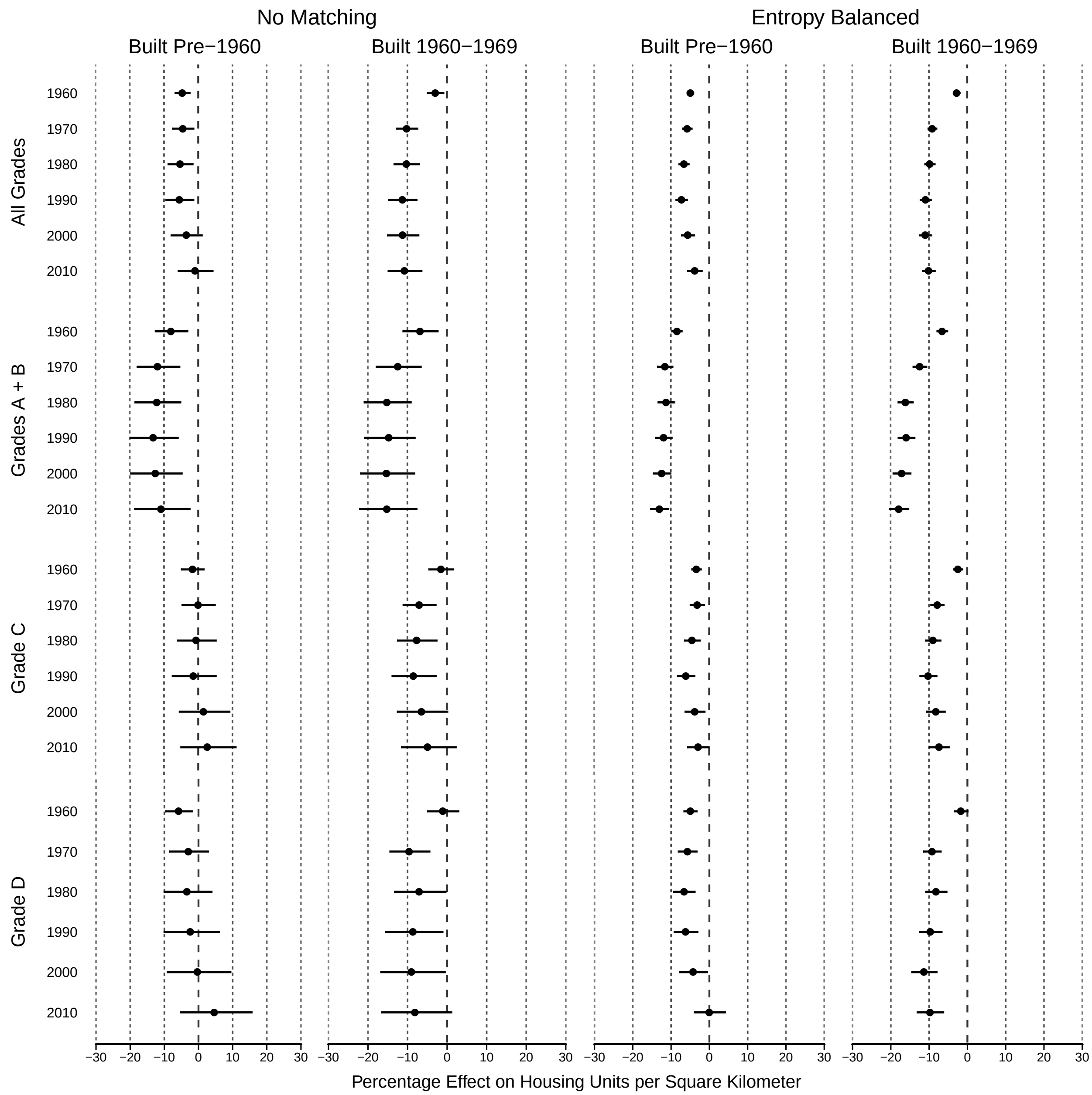


Figure A-11: Effect on housing-unit density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969 (dropping HOLC-tracts with large decadal swings in population or housing). Horizontal lines are 95% confidence intervals.

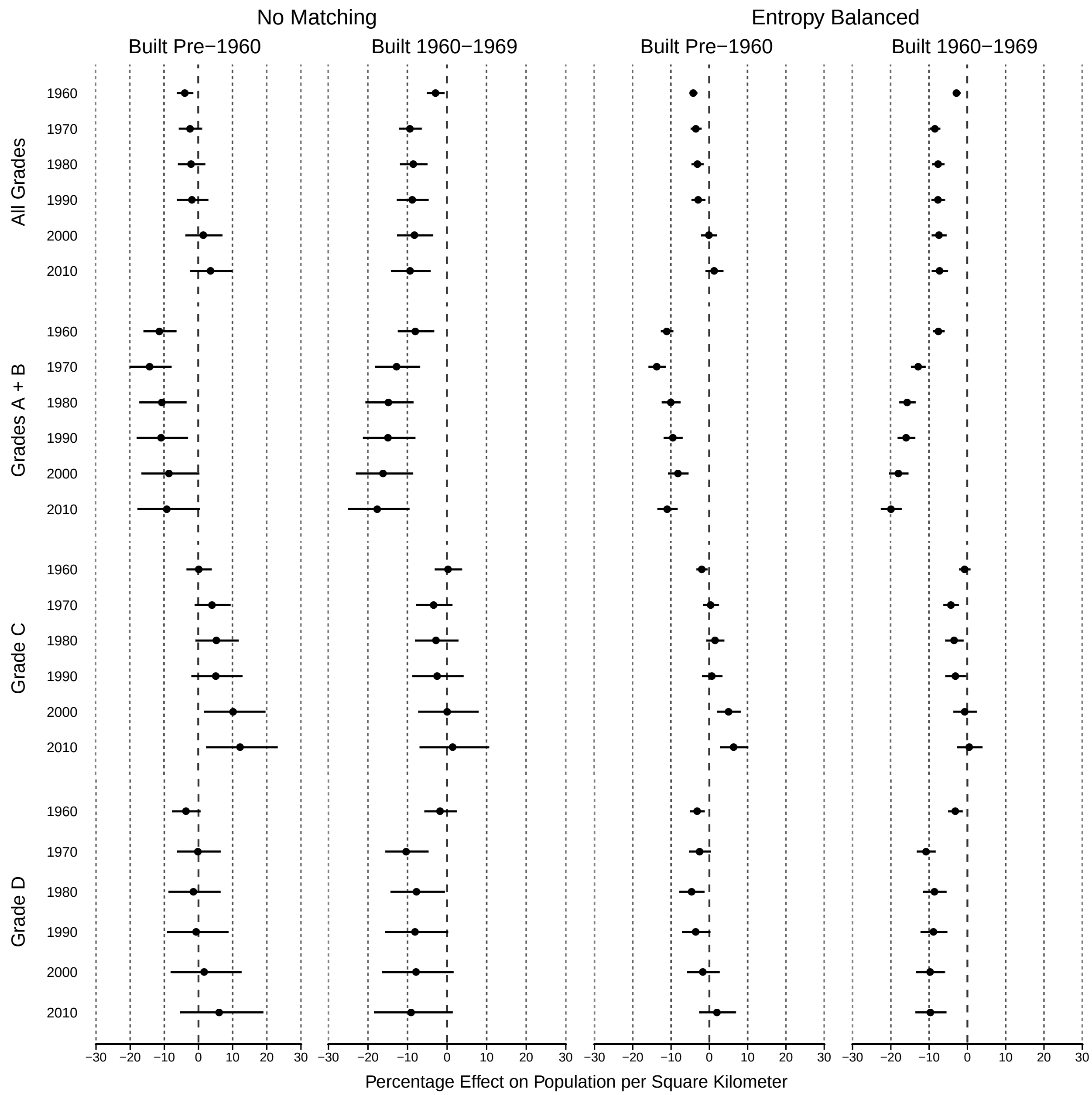


Figure A-12: Effect on population density from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969 (dropping HOLC-tracts with large decadal swings in population or housing). Horizontal lines are 95% confidence intervals.

Additional Results

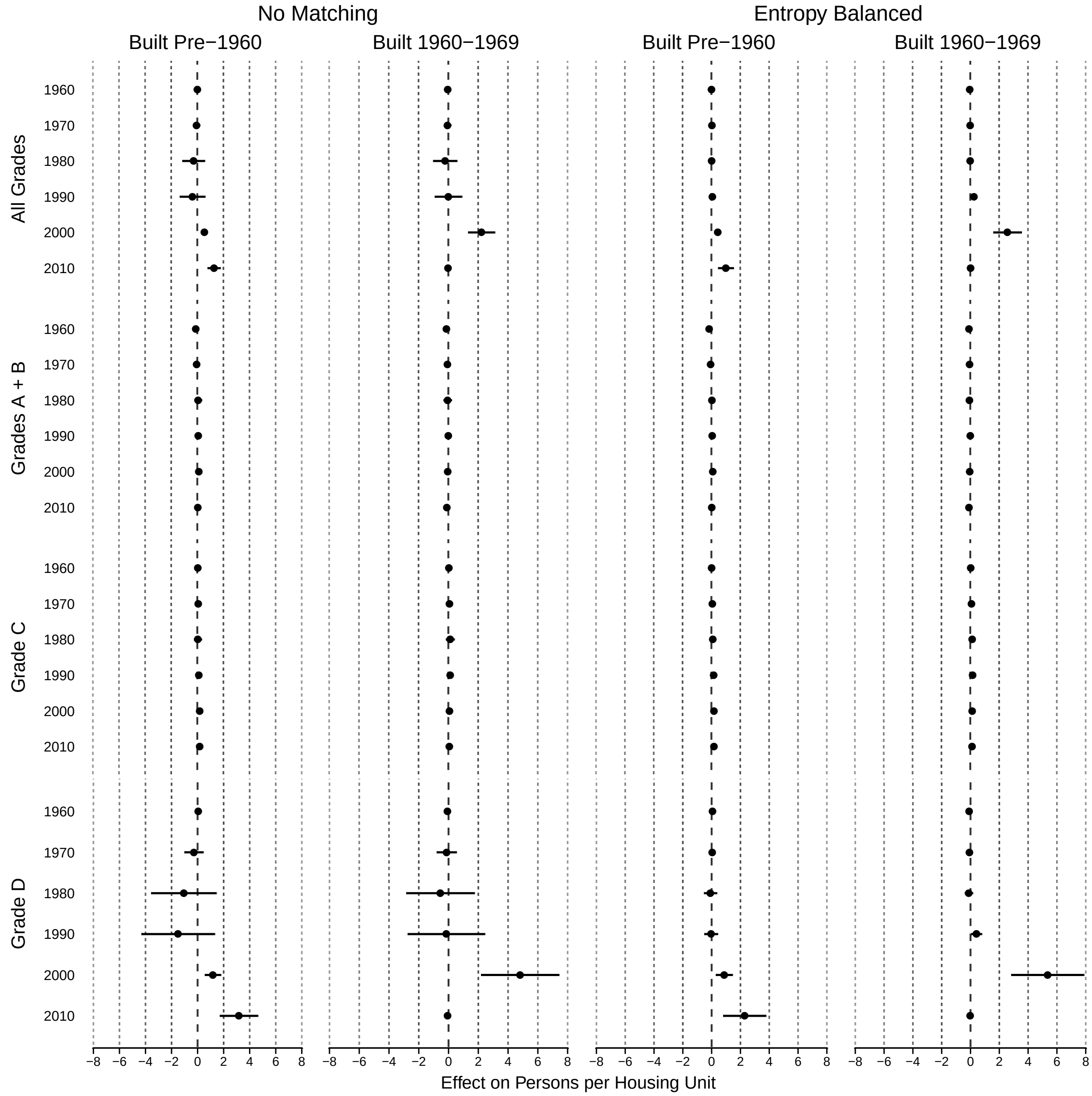


Figure A-13: Effect on population per housing-unit from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969. Horizontal lines are 95% confidence intervals.

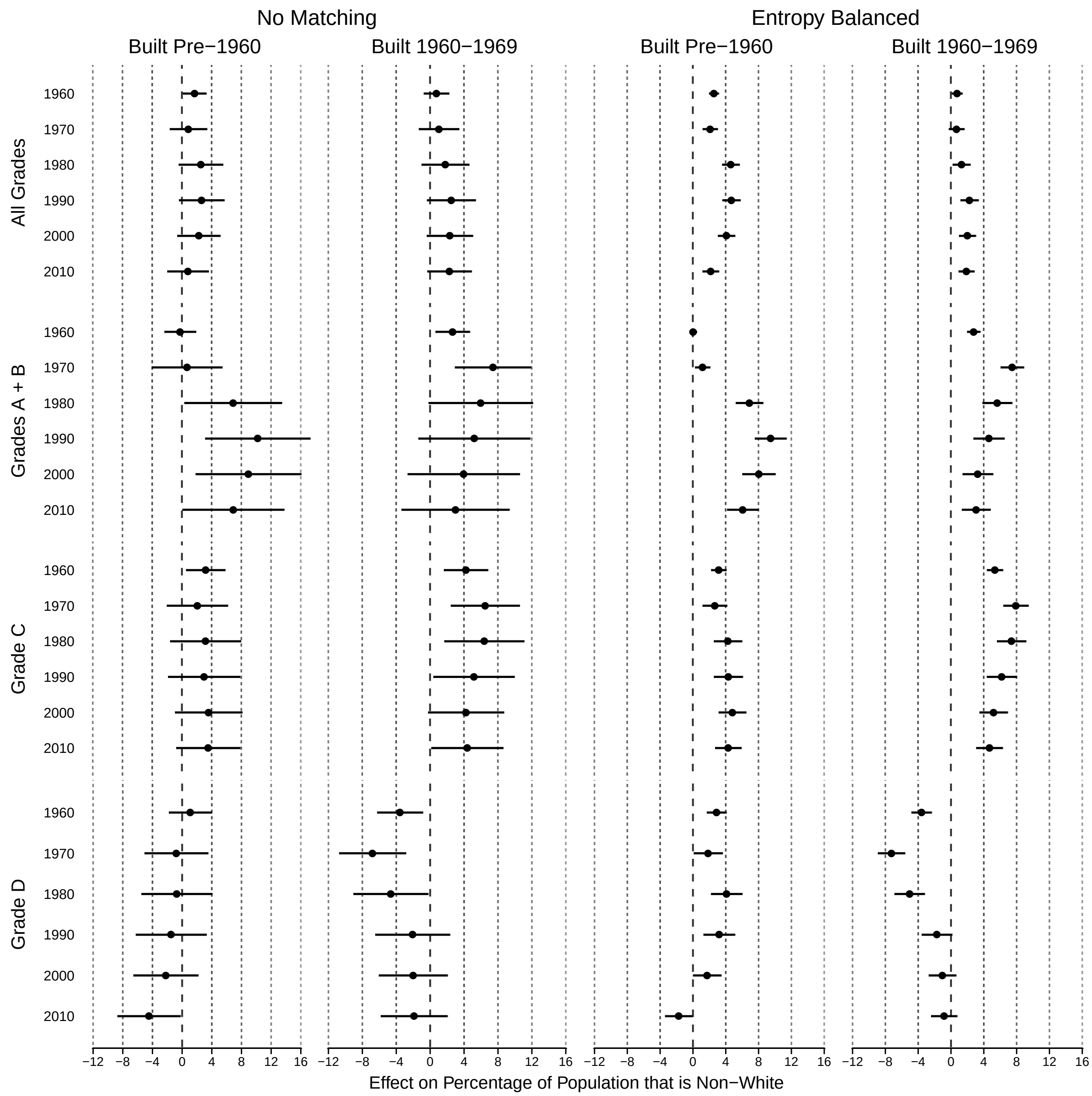


Figure A-14: Effect on percentage of population that is non-white from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969. Horizontal lines are 95% confidence intervals.

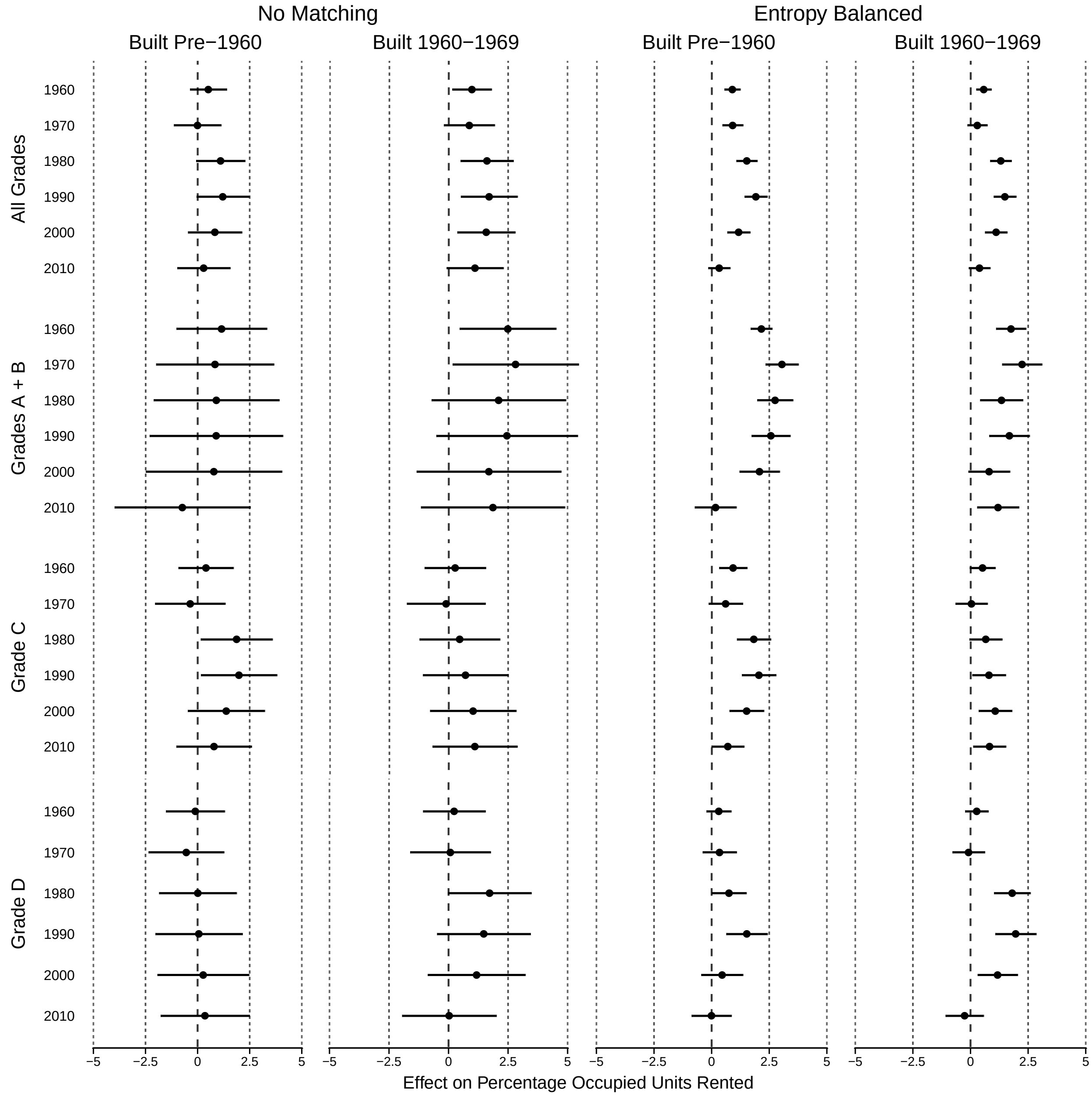


Figure A-15: Effect on percentage of occupied housing units that are rented from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969. Horizontal lines are 95% confidence intervals.

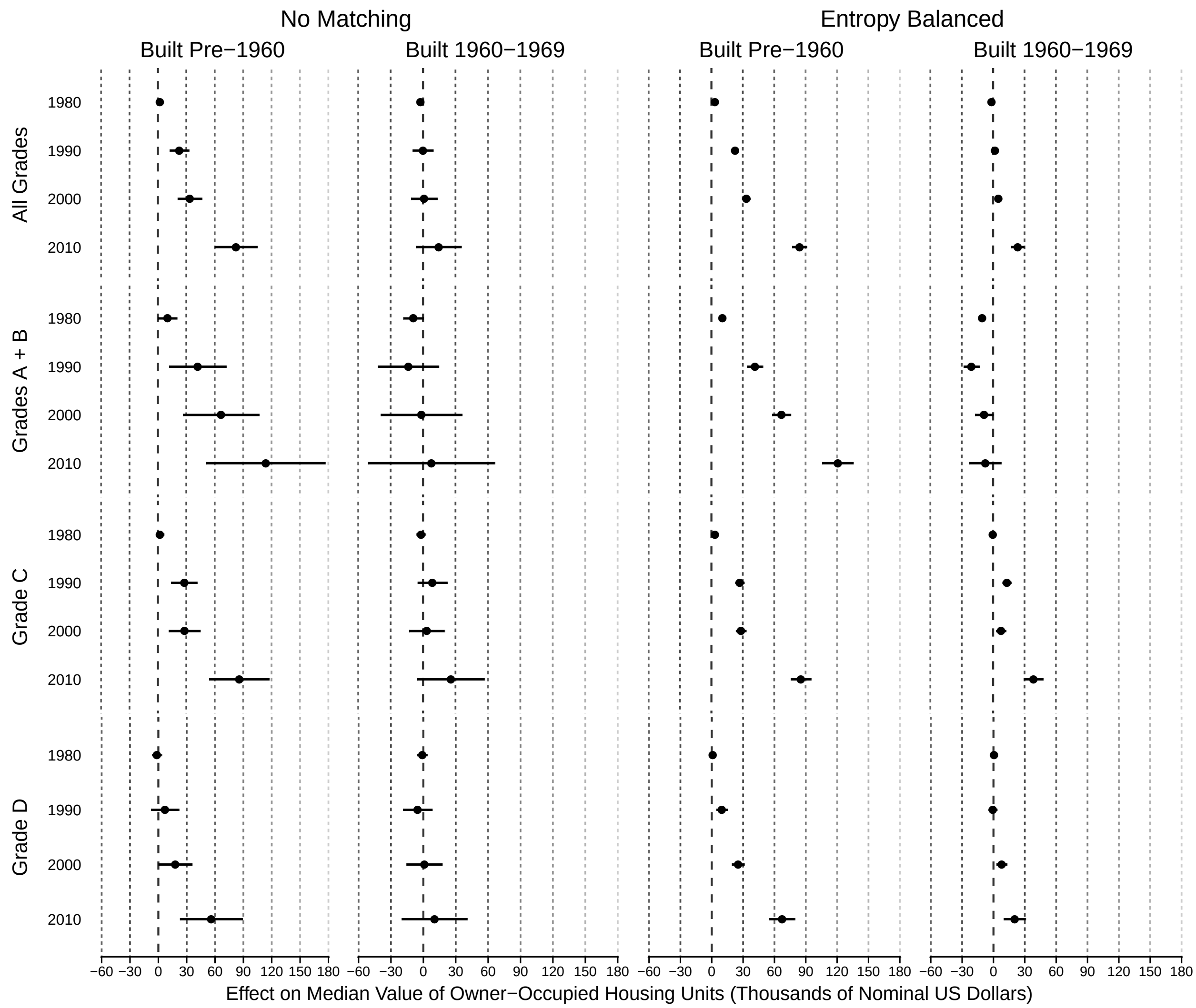


Figure A-16: Effect on median value of owner-occupied housing units from placement of a highway through a HOLC-tract, for Interstate highways built before 1960 and 1960–1969. Horizontal lines are 95% confidence intervals.