

Infrastructure Costs

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May 2019

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The state of US roads and other infrastructure generates considerable concern and most commentators claim that construction costs are very high. Yet we know surprisingly little about costs across time and place. We help to fill this gap by using data we digitized on the Interstate highway system—one of the nation’s most valuable infrastructure assets—to document spending over the history of construction.

We make three main contributions. First, we find that spending per mile on Interstate construction increased more than three-fold (in real terms) from the 1960s to the 1980s. We date the inflection point of increase to the early 1970s. We further show that neither changes in the observed geography of spending nor increases in material and labor prices explain these changes. Second, we document substantial unexplained variation across states in Interstate construction costs. Third, we provide suggestive evidence of the determinants of cross-state and cross-time variation in spending per mile. Looking over time, the increased spending per mile coincides with the rise of “citizen voice” in government decision-making in the early 1970s. We also largely rule out several common explanations for rising costs.

JEL codes: H4, H5, H7, K0, N4, N7, N9, R4

Keywords: infrastructure; highways; public participation; corruption; environmental review

1. Introduction

The United States spends an enormous amount on infrastructure—over \$400 billion a year.¹ Despite this, engineers report a backlog of \$1.5 trillion of needed infrastructure and give US infrastructure a grade of D.² Many have looked to an increase in infrastructure spending as a

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¹ Shirley, Chad, “Spending on Infrastructure and Investment,” Congressional Budget Office (Mar. 1, 2017), <https://www.cbo.gov/publication/52463>.

² See 2017 Infrastructure Report Card, <https://www.infrastructurereportcard.org/>.

balloon to improve flagging productivity growth³ and reduce inequality.⁴

Despite this enthusiasm for increased investment, there is a widespread belief that the US now gets less for this spending – both less than it used to, and less relative to other countries.⁵ For example, evidence suggests that recent transit projects are more expensive in the US than in the rest of the world (Rosenthal 2017, Gordon and Schleicher 2015, Levy 2013). Apart from these sources, there is very little credible evidence on whether spending per mile in the US has gone up over time, or whether some locations have higher or lower costs. Much of the cutting edge in this area consists of *New York Times* exposés⁶ and blog posts.⁷ The issue of infrastructure costs is particularly important as calls for increased infrastructure spending come from both the left and the right, combined with prescriptions for dealing with higher perceived costs (Cama 2017).

The lack of scholarship on the cost of infrastructure is likely attributable to several factors. With so many political, legal, and economic differences across countries, international comparisons are difficult. Even domestic comparisons across time and space face the challenge of a diversity of infrastructure that bedevils cross-project comparisons. As well, the legal background needed to understand infrastructure spending and its potential drivers is a strong deterrent to research. Finally, granular data on infrastructure spending are limited.⁸

We aim to help fill this evidentiary gap by documenting and analyzing spending on new construction of the US Interstates over the course of the second half of the twentieth century. Interstate highway construction is of particular interest because it is one of the largest infrastructure projects in American history, while at the same time sharing features with many other forms of infrastructure construction, such as significant federal funding contributions,

³ See White House, “Infrastructure Investment to Boost Productivity” (Feb. 21, 2018).

⁴ Bouchard, Mikayla, “Transportation Emerges as Crucial to Escaping Poverty,” *New York Times* (May 7, 2015), A3.

⁵ See, e.g., Long, Elliott, “Soaring Construction Costs Threaten Infrastructure Push,” *Progressive Policy Institute* (2017); Smith, Noah, “The U.S. Has Forgotten How to Do Infrastructure,” *Bloomberg* (2017), <https://www.bloomberg.com/view/articles/2017-05-31/the-u-s-has-forgotten-how-to-do-infrastructure>. See also Taylor, Brian, “Why California Stopped Building Freeways,” *Access*, 3 (1993) <https://www.accessmagazine.org/fall-1993/why-california-stopped-building-freeways/>; Beyer, Scott, “7 Reasons U.S. Infrastructure Projects Cost Way More Than They Should,” *CityLab* (2014) <https://www.citylab.com/life/2014/04/7-reasons-us-infrastructure-projects-cost-way-more-they-should/8799/>.

⁶ See Rosenthal, Brian. “The Most Expensive Mile of Subway Track on Earth,” *New York Times* (Dec. 28, 2017), A1. <https://www.nytimes.com/2017/12/28/nyregion/new-york-subway-construction-costs.html>.

⁷ See <https://pedestrianobservations.com/construction-costs/>.

⁸ Many researchers have used detailed state department of transportation bid data; unfortunately, these are quite difficult to standardize nationally. We are aware of no project that has done so.

being subject to various laws such as those pertaining to the environment and labor, and often leading to political controversy. In addition, and usefully for our analysis, it is a relatively uniform product across space and time, particularly in comparison with other big-ticket items such as mass transit and airports. This relative uniformity makes for easier comparisons across time and space. At the same time, because states were in charge of construction, there is rich potential for geographic variation. Our approach is to study trends in cost over time and space, learning about the United States by exploiting variation within the country (e.g., Chetty et al. 2014).

To conduct the study, we digitize annual state-level data on spending from 1956 to the present. Along with Leff Yaffe (2019), we are the first to use more than a few years of this data⁹ and to combine these data with the number of Interstate miles completed in each year (Baum-Snow 2007). In addition, we add numerous other sources to measure the geographic, political, and legal determinants of spending. While the spending data are at the state level, we observe the precise location of Interstate segments by date of completion, which allows us to undertake more granular analysis of segment attributes over time.

We make three main contributions. First, we document the change in Interstate spending over time.¹⁰ This documentation reveals a dramatic increase in spending per mile of constructed Interstate. States spent approximately three times as much (in real terms) to construct a highway mile in the 1980s as they did in the early 1960s. This temporal increase persists even controlling for the geographic location of Interstate construction.

Our second contribution is documenting substantial variation in spending per mile across states not explained by observable differences in geography. This finding resembles work on health care spending, which indicates a two to four-fold difference between the highest and lowest levels of observed spending among U.S. hospital referral regions after accounting for geographical and other “uninteresting” covariates (Skinner and Fisher 2010, Cooper et al. 2018).

⁹ Using the same data for the period 1990-1994, Smith, Haefen, and Zhu (1999) estimate a positive, statistically significant effect of environmental regulations on highway expenditures by comparing federal roads subject to certain environmental regulations with state roads that are not.

¹⁰ Historically the Department of Transportation produced a Bid Price Index, but it was canceled out of reliability concerns. In any case, it only measured input prices (e.g., the price of concrete), not final spending, which includes both prices and quantities. So it would not capture, for example, increased use of concrete to build sound barriers. DoT later produced the NHCCI starting in 2003, which again was rehauled out of reliability concerns and again only measured input prices. FHWA, National Highway Construction Cost Index (NHCCI) 2.0 (2017), <https://www.fhwa.dot.gov/policy/otps/nhcci/desc.cfm>.

Our third contribution is to marshal suggestive evidence on the drivers of these spending patterns. Several prominent potential explanations are likely *not* important. First, observable changes in geography do not substantially change the overall pattern of cost increase, providing some reassurance that highway planners did not leave the “hardest” sections until last. Second, we show that changing construction material and labor prices explain virtually none of the increase in spending over time. Analogizing to an important question in the healthcare literature (Anderson et al. 2003, Skinner and Fisher 2010; Cooper et al. 2017), this result suggests that increases in quantities, rather than increases in prices, drove the increase in costs. Third, we show that the increase in spending per mile was overwhelmingly driven by the costs of construction itself, not the costs to attain rights of way or to conduct preliminary engineering: these latter costs are never very large and their share of total spending does not increase over time. So it is unlikely that changes in eminent domain law substantially increased costs, at least directly. Fourth, anything constant across time cannot alone explain the increase. For example, because the United States is and was a common law country, the cost increase we document cannot be due to the common law alone (though it could be an important precondition). More generally, whereas many explanations for high US infrastructure costs focus on features of the United States that are little changed since the 1960s, our results suggest the importance of focusing on features that have changed. And fifth, we are unaware of any large changes in federally-mandated Interstate standards that could have driven the increase.

At least two contributing explanations do appear consistent with the data. First, the temporal pattern in the increase in spending per mile is consistent with the rise of social movements, legislation, and judicial doctrine in the late 1960s and early 1970s that increased “citizen voice” in government decision-making.¹¹ The cross-sectional pattern of cost increases is also consistent: states that one would expect to have more “citizen voice” experience larger cost increases. If citizen voice drives spending, it is not predominantly through direct planning or litigation costs, as increases in spending on these items is insufficiently large to account for the increase. Citizen voice could, however, yield more expensive construction in the form of more

¹¹ Several studies suggest that environmental review may increase costs. Smith, Haefen, and Zhu (1999) compare expenditures on Federal-Aid highways subject to environmental regulations with state roads not subject to those same regulations, finding that measures of environmental resources like counts of endangered species and proximate Superfunds are positively associated with increased construction costs of Federal-Aid highways but not of state roads. Other scholars find that specific features of environmental review, such as litigation costs, mitigation costs, or project delay, increase spending (Olshansky 2007, Greer and Som 2010, deWitt and deWitt 2013).

expensive routes and auxiliary structures that reflect citizen concerns. Consistent with this explanation, we show that the number of ancillary structures (e.g., bridges and ramps) and the wiggleness of routes increase during roughly the same time period. A second consistent explanation is increasing use of labor, as states that have higher unionization or presidential Democratic vote shares also experience larger cost increases.

To be clear, our project is on only how much spending per mile of Interstate highway varies across time and space, and what may drive that. Since we do not capture other features of construction, like the possibility that different (and potentially costlier) construction techniques could cause less damage to local communities or the environment, we cannot make welfare statements.

This Article is organized as follows: Section 2 describes the history of the Interstate system. Section 3 describes our data. Section 4 documents construction spending over time and space. Section 5 analyzes possible explanations for these patterns. Section 6 concludes.

2. The Interstate System

In this section we discuss four key points of institutional background necessary to understand states' ability to make choices about Interstate construction. We discuss the determination of routes, the timing of Interstate construction, how states receive funding, and federal construction requirements.

Route determination. The Federal-Aid Highway Act of 1944 established the National System of Interstate and Defense Highways as a 40,000-mile planned network of highways spanning the United States. The highways were envisioned as a means to encourage economic development, speed traffic, and provide for the national defense (Eisenhower 1956). From 1944 to 1946, states submitted proposals and negotiated with the federal government, generating a high-level 1947 map (Appendix Figure A1) that largely corresponds to the eventually-built system. Over the next eight years, the state and federal governments collaborated to produce more specific plans compiled in the so-called 1955 "Yellow Book." Subject to a Federal Highway Administration (FHWA) approval process, ultimate routes were typically close, though not necessarily identical in the specific location, to those planned in the late 1940s and early 1950s.

Progress was minimal until 1956, when the Federal-Aid Highway Act of 1956 (1956 Highway Act) made major appropriations and extended the planned system by roughly 1,000

miles for a total of 41,000 miles. Thus, by the time states received substantial federal funding for construction, the largest decisions over route existence and location were mostly complete. Over the 20 years following 1956, roughly 2,000 additional funded miles were designated as part of the Interstate system, along with roughly 6,000 unfunded ones (e.g., those already existing in 1956 or funded by tolls and thus ineligible for funding), producing today's roughly 49,000-mile system (FHWA 2017b).

Timing. Though Interstate construction lasted for over 40 years, most miles were constructed in the 1960s and 1970s—54 and 31 percent respectively. This pattern is clear in Appendix Figure A2, which indicates miles constructed in each decade with a wide line. Looking across states, almost all states did some construction in each of the 1950s, 60s, 70s, and 80s; just under half did in the 1990s. Rather than starting at one end of a highway and continuing along the route, most Interstates were built in pieces, with those pieces eventually connecting to complete the throughway. This pattern suggests substantial discretion afforded to the states in the timing and ordering of construction. Appendix Figure A2(i) from the 1950s shows this type of progression.

Funding. Funding for the system was overwhelmingly federal. The 1956 Highway Act set the federal government contribution for new highway construction at 90 percent of the estimated cost of the Interstate system, with the remaining 10 percent to be borne by the states.¹²

Broadly speaking, there was no cap on the total amount a state could spend to construct an approved Interstate highway route, so long as the state could cover the upfront costs and secure FHWA approval over successive Congressional appropriations. In any given year, a state's receipt of funds was limited by the demands from other states and the amount of federal funds authorized and appropriated for that year. However, from a total cost perspective, a state could spend more on an Interstate simply by building it more slowly, on the assumption that Congress would continue to authorize increased revenue into the Highway Trust Fund.

¹² In states where more than five percent of total land area was comprised of "unreserved [Federally owned] public lands and nontaxable Indian lands," the federal government paid up to half of the remaining ten percent of Interstate construction costs (23 U.S.C. § 120(a)(1)). Ten to thirteen Western states benefited from this additional funding, with Nevada, Arizona, and Utah receiving roughly 95 percent reimbursement. Lewis, David L. *State Highway System: Issues and Options*. Washington, D.C.: Congressional Budget Office, 1982, 10 n.1, <https://www.cbo.gov/sites/default/files/97th-congress-1981-1982/reports/doc19b-entire.pdf>; Department of Transportation, Federal Highway Administration, *Notice: Sliding Scale Rates In Public Land States - Rates Effective March 17, 1992*, N 4540.12, (Washington, D.C., 1992), <https://www.fhwa.dot.gov/legisregs/directives/notices/n4540-12.cfm>. To account for this difference between states, we scale back our observed federal spending in proportion to the additional reimbursement.

We now delve deeper into this funding process, beginning with the process of annual apportionment to and across states, and then analyzing the determinants of the timing of state spending. Crudely, the federal government financed Interstate construction via the revenue garnered from the portion of the federal gas tax dedicated to highway funding. This revenue was credited to the Federal Highway Trust Fund and was apportioned among the states by formula (Weingroff 1996). The Byrd Amendment to the Federal-Aid Highway Act of 1956 prevented the program from running a deficit by requiring the Secretary of Commerce “to reduce the apportionments to each of the States on a pro rata basis” when a deficit existed (Congressional Quarterly Almanac 1956). This amendment, together with increased costs, required occasional increases in the gas tax, as well as the imposition of new taxes (FHWA 2017b). The last Interstate construction funds were apportioned in the 1996 fiscal year (FHWA 2017a).

In form, Interstate construction was a reimbursable program, meaning that the federal government paid states back for money spent on building the Interstates (FHWA 1983a). The process generally worked in the following manner. Congress, through legislation, authorized each year an amount of money for Interstate construction on the basis of the estimated cost to complete the System, and on the health of the Highway Trust Fund. A certain amount of this authorized money was deducted to pay for FHWA operations and research (FHWA 1983a). The remaining money was then apportioned to the states.

For all years after the first three,¹³ states were apportioned funds in proportion to the estimated cost to complete their remaining planned Interstate mileage. These “Interstate Cost Estimates” came from state submissions to Congress, which were prepared in conjunction with federal oversight and contained detailed estimates of costs by input (e.g., right of way purchase, planning and construction) for planned Interstate segments (e.g., a 2-mile segment of I-10) (Weingroff 1996). Congress required these submissions roughly every two to three years from 1958 to 1991.

Once apportioned, the money was available to the states for obligation on a per-Interstate-project basis. An obligation is a guarantee from the federal government to reimburse a

¹³ In the first three years of the Interstate program, the annual distribution of apportionments among states was determined by the population, area, and mileage formula used for determining appropriations in a much less ambitious earlier system.

state for the eligible portion of a project's cost. To obtain an obligation, states¹⁴ submitted specific projects for FHWA approval (FHWA 1983a). States generally had a two-year time limit to apply for funding and receive an obligation. If a state failed to obligate apportioned funds within that time period, then the apportioned funds would be revoked and apportioned to other states on the basis of the funding formula. Once a project was approved by the FHWA, the state was free to begin work on the Interstate project. Whether a state was reimbursed over the course of the project or upon the project's completion varied over time and by state, but states were generally reimbursed for expenditures upon the submission and certification of vouchers documenting their expenditures for the FHWA (FHWA 1983a, Manes 1964).

This entire apportionment-obligation-expenditure process had a varying and uncertain time window. While states could wait no more than two years between apportionment and obligation before they would lose funding, the time period between obligation and expenditure was less certain. There was generally no limit between the date of obligation and date of expenditure, though states sometimes had to meet timelines for the commencement (but not termination) of construction.¹⁵ If an approved project was delayed, for example, there could be a long gap between the date of expenditure and the date of actual reimbursement.

This funding scheme applied only to new construction, not maintenance, which is consistent with our focus in the data analysis. In some limited cases, states were able to use small amounts of Interstate funds on non-Interstate projects; we adjust for this in our data construction.¹⁶

¹⁴ Later, after the passage of the Federal-Aid Highway Act of 1973, incorporated cities could also submit Interstate projects for Federal matching if 1) the relevant highway segments were designated as part of the Interstate system as of June 1, 1973, 2) the segments were entirely within the boundaries of the city, and 3) the city could pay the non-Federal share. 23 U.S.C. § 103(h) (1976) (as amended in 1973 by Federal-Aid Highway Act of 1973 § 110, Pub. L. No. 93-87, 87 Stat. 250, 256 (1973)).

¹⁵ For example, projects that made use of the federal government's so-called "right-of-way revolving fund," which provided advance funding for land acquisition, were required for a time to commence construction on the purchased land not less than two years and not more than seven years from the end of the fiscal year in which the funds were approved. Federal-Aid Highways Act of 1968 § 7(b), Pub. L. 90-495, 82 Stat. 815, 818-19 (1968) (codified at 23 U.S.C. § 108(c)(3), amended 1973, repealed 1998).

¹⁶ Three programs affect our estimation of Interstate expenditures over time. First, the Withdrawal-Substitution program allowed states to withdraw planned Interstate routes and use the money instead for mass transit projects or non-Interstate road projects. See Federal-Aid Highway Act of 1973 § 137(b), 23 U.S.C. § 103(e)(2) (2012). Second, the Minimum Allocation rule required that states receive at least half a percent of a year's Interstate Cost Estimate apportionment, regardless of the estimated cost-to-complete of their Interstates (states could thus spend in excess of their cost-to-complete on other Federal-Aid eligible roads). See Federal-Aid Highway Act of 1970 § 105(b)(1), Pub. L. No. 91-605, 84 Stat. 1713, 1716 (1970). Lastly, the Minimum Percentage Allocation rule required that the total amount of Federal-Aid money apportioned to a state (Interstate construction funds as well as Federal-Aid Primary, Secondary and Urban funds) be at least a certain percentage of yearly tax revenues that the state's drivers contribute

In 1956, the FHWA estimated that the network would cost \$25 billion in federal funds, or \$192 billion in 2016 dollars, and take thirteen years to complete (DOT 1958, p. 7). In the end, it totaled over \$504 billion (2016 dollars) in federal spending, and construction took more than forty years.¹⁷

Construction standards. Finally, in exchange for the receipt of Interstate construction funds, states were required to construct to “Interstate standards.” In general, Interstates had to have at least two lanes in both directions,¹⁸ full control of access, minimum design speeds of 50-70 mph, minimum lane widths, and adequate design to support the traffic volume expected for 1975 (a requirement that was later changed to the volume expected 20 years from project completion).¹⁹ Mileage that received federal funding could not have tolls.²⁰ Congress also applied the Davis-Bacon Act to Interstate construction, which required that Interstate construction laborers be paid the prevailing wages of the area in which the project was carried out (Weingroff 1996). States were allowed to spend Interstate funds on right-of-way acquisition.

3. Data

A primary contribution of this paper is marshalling data to describe the long-run trajectory of Interstate expenditure per mile by state and year. We do this by combining data on Interstate mileage over time with data on Interstate spending over time.

to the Highway Trust Fund. See Highway Improvement Act of 1982 § 150, 23 USC § 157 (1988). In the appendix, we explain in more detail the history of these programs as well as how they affect our estimates.

¹⁷ Based on periodic Interstate cost estimates that we inflate period by period to 2016 dollars.

¹⁸ This standard was put in place by the Federal-Aid Highway Act of 1966 and codified in 23 USC §109(b). Prior to the enactment of this legislation, certain Interstate segments (rural, lightly-traveled ones) were allowed to be constructed to a two-lane standard (one lane in each direction) and still receive full federal funding. The 1966 Act required that these lanes be brought up to the four-lane standard. This may contaminate our spending data, though likely only to a small extent. On the basis of congressional hearings over the 1966 Act, spending to upgrade two lane segments under construction at the time of the legislation’s passage was likely included in subsequent years of our expenditure data (Hearings 1965, Hearings 1966). But the hearings, as well as the 1968 Interstate Cost Estimate, suggest that this would have amounted to \$335 million (DOT 1968, p. 12). Since this money was provided in the 1968 apportionment, inflating from 1969 to 2016 dollars provides a lower bound of approximately \$2.19 billion (2016 USD) of possible additional spending. Because this is so small relative to the \$504 billion (2016 USD) spent over the course of Interstate construction, we think it is unlikely to bias our estimates of spending change over time.

¹⁹ See “A Policy on Design Standards,” American Association of State Highway Officers (AASHO), 1956; “A Policy on Design Standards-Interstate System,” AASHTO, 1991 (codified via 58 Fed. Reg. 25939 (1993) at 23 U.S.C. § 625.4(a)(2) (1995)) [hereinafter, DS-4].

²⁰ Some of the roads incorporated into the system were toll roads. While they were designated as part of the Interstate System and counted towards the 41,000-mile limit, they were ineligible for federal Interstate construction funds (FHWA 2018b).

For highway mileage over time, we use Baum-Snow (2007)’s digital map and his digitization of the *Form PR-511 Database* maintained by the FHWA. This database tracks the date of opening for each separately opened section of the Interstate Highway System. Using both the map and data, we can identify the number of Interstate miles completed by state, county, and year from 1956 to 1993, by which point 98% of Interstate mileage had opened. Our data contain over 98 percent of the system’s funded mileage built by 1993 (FHWA 1998). Though we will often aggregate within larger geographies like states, our basic unit consists of one-mile “segments” of Interstate that partition the dated sections of the *Form PR-511 Database*. We exclude Hawaii and Alaska, for which opening year is not recorded in our data.²¹

We complement these mileage data with 1956 to 2014 spending data that we digitized from the Federal Highway Administration’s *Highway Statistics* series and report in 2016 dollars. With minor exceptions, this spending is on new construction. New construction includes land acquisition and right of way, preliminary engineering, and spending on the physical building process. It excludes maintenance, resurfacing, and other post-construction categories of spending. As we explain in Supplemental Appendix A,²² we make small adjustments using auxiliary data from the *Highway Statistics* and elsewhere to account for these minor exceptions (small amounts of money that, in some cases, could be used for non-Interstate purposes). Isolating spending to just new construction is a major feature of the analysis, as it allows us to study all spending on a fairly uniform thing: a newly-constructed mile of Interstate highway.

We observe expenditures in the year that the federal government reimburses states for obligated expenditures—typically in the year in which the state spent the money. We observe miles, however, in the year in which they are completed (opened to the public). This generates a mismatch between the two data series, including 413 state-year observations with expenditures but no completed miles (roughly 25 percent of state-years).

To partially address this mismatch, we let the data tell us how much spending from each prior year relates to a given mile opening, producing an adjusted measure of Interstate expenditures. Specifically, we regress the number of miles opened in a given year on leads and lags of spending. This regression (Appendix Table A1) associates a mile constructed with 40.3 percent of spending from the current year, 33.5 percent from the previous year, and 15.1 percent

²¹ We also exclude the District of Columbia, which is a major outlier as a one-city district.

²² Available from the authors.

from two years prior to the current year. This result accords with other data, which show that 72 percent of segments for which we observe the start and open date were constructed in no more than three years. Because our spending data begin in 1956, and because we include in a given year data from two years prior, our data series generally begin in 1958. In later regressions we show that the attributes of completed miles are associated with spending in expected ways, suggesting that our allocation of spending to miles has empirical bite.

We combine these expenditure and mileage data with a variety of other data sources described briefly below and detailed in Supplemental Appendix B.²³ To measure the underlying (human and physical) geographic and environmental conditions of the sites of Interstate construction, we assemble measures of urban development; rivers, wetlands, and other waters; and terrain steepness. We measure the first by the population density associated with each segment using the population of the Census tract in which that segment was built in the closest Census year.²⁴ We measure the degree to which each segment was built through wetlands, rivers, and other waters by the share of its length built through these features. We measure the terrain steepness as the average slope within fifty meters of the path that a highway segment traverses.²⁵ In robustness checks in the Appendix, we include other measures, including climate and an ecological categorization, as well as alternative measures of other geographic variables.

We also measure characteristics of the construction itself. We calculate the “wiggleness” (formally, tortuosity) of each segment of Interstate as the ratio of its true length to the as-a-crow-flies distance between its endpoints. We measure the median value of owner-occupied single-family homes near a segment as the median value reported in the nearest decennial Census for the tract (or, if not available at the segment’s date of construction, county) through which the segment was built. We measure segments’ number of lanes in the Highway Performance Monitoring System’s 2016 road inventory (counting lanes in both directions).²⁶ We also measure the length of supporting highway structures associated with each segment of Interstate highway

²³ Available from the authors.

²⁴ The Census tracted the nation gradually from the 1940s on, usually from the most urban areas out, so if a segment was built through an area not yet tracted by the Census at the time of construction, we use county-level population density.

²⁵ More precisely, we observe slope measures in a national grid of 1 arcsecond cells. For each segment, we average the slope of all cells within fifty meters of the segment.

²⁶ Although, for some segments of Interstate, the number of lanes that comprise it has likely grown since the segment’s construction, we think this current measure of lanes is nonetheless useful.

as the sum of Interstate bridge and ramp lengths.²⁷ To measure how slowly segments are built, a measure available for 3.3 percent of segments completed before 1966 and 80.3 percent of segments completed after, we use the number of years between the reported year construction began on the segment and the reported year the segment opened to traffic.²⁸

We also include measures of politics. As a measure of fiscal responsibility, we include the Standard and Poor's bond rating by state, which we convert to a numerical score using interest rates historically associated with each bond rating. We use a 1999 state-level measure of corruption from Boylan and Long (2003). We use the statewide percentage vote share for the Democratic presidential candidate in election years, and we linearly interpolate in the intermediate years. We also use the number of land use cases per ten thousand people, as constructed by Ganong and Shoag (2017), partly as a direct measure of something that could make construction costlier and partly as a correlate of local opposition to construction. We measure how much jurisdictional fragmentation there is where each segment is built by counting the number of local governments operating within the segment's county.

Table 1 provides summary statistics on the subset of these measures used in our primary analyses.

4. Documenting Interstate Highway Spending Over Time and Space

We now turn to our first two significant contributions, producing two novel stylized facts about Interstate spending over time and space. First, there is a dramatic increase in spending per mile (which we will call by the shorthand “cost”) from 1956 to 1993 – with roughly a tripling between the 1960s and 1980s. We also show that the physical form of Interstates has changed over time, generally in a way that has become costlier. Second, we find substantial and persistent variation in costs across states, such that the 25th percentile state (Mississippi) spends less than half per mile what the 75th percentile state (Virginia) spends. All these patterns remain even after controlling for observable geographic determinants of highway cost.

²⁷ Note that we measure these structures as of 2016, not as of when they were built, which could attenuate results. The majority of structures we observe are ramps, though many are bridges.

²⁸ Because these reported dates are only available for aggregations of the segments we observe (“sections” of Interstate), we assume that the reported dates for each segment coincide with those of the section to which the segment belongs.

To assess how spending changes over time, Figure 1 presents national spending per mile constructed from 1956 to 1993 (that is, total highway expenditures in a given year divided by miles completed in that year). The lighter line in the figure shows annual data, and the darker line shows a 3-year moving average. Though there is substantial noise in the annual data, the overall pattern of increase is clear. By 1990, the federal government spent three times as much to build a highway mile as it did in the 1960s, increasing from roughly \$8 million per mile to roughly \$25 million per mile (all 2016 dollars).

There are at least two reasons to expect that states should spend less per mile over this period, rather than more. First, the mismatch between spending and mileage in our data pushes miles forward relative to spending. All else equal, in the early years of the program this should yield spending on miles that will not open until later, driving up spending per mile. In the later years, as the Interstate program decelerated, mileage completion picks up and spending declines, likely yielding decreased spending per dollar. Second, there have been many technical innovations in highway construction since 1956, which should decrease costs. Construction equipment has become more sophisticated and building materials have also improved. For example, using high-strength steel reinforcement—initially introduced in other forms of construction in the 1960s—was estimated to reduce by 30 percent the cost of reinforcing a bridge during construction by the 1980s (National Academy of Sciences 1984, p. 26). Laser-guided survey and excavation equipment also improved productivity (Yates 1988, p. 71).

Despite these countervailing forces, we observe a dramatic increase in spending per Interstate mile. One natural explanation for this finding is that states construct “easy” miles first. We test this explanation by dividing the idea of “easy” miles into geographically and politically easy construction. First, we consider geographically easy miles. In this section we show that even conditional on observable geographic attributes of highway segments, per mile spending still increases substantially. We leave the possibility of differential timing of politically easy miles – which we view as a mechanism – to the following section.

To evaluate whether the timing of construction of geographically easy miles explains the increase in spending per mile constructed, we assess whether the temporal pattern of the increase is robust to controlling for geographic covariates and state fixed effects. Specifically, we estimate

$$\frac{\text{spending}}{\text{miles}}_{st} = \beta_0 + \beta_1 \text{period}_t + \beta_2 \mathcal{G}_{st} + \beta_3 I_s + \varepsilon_{st} \quad (1)$$

Indices are s for state and t for year.

The primary coefficients of interest are the coefficients β_1 on the period indicators. To abstract from noisier annual measures and to reduce concerns about having missing data because no miles open in a given period, we construct period bins (1958-1963, 1963-1970, 1971-1975, 1976-1981, 1982-1987, and 1988-1993) and focus for the temporal pattern from these periods. Both here and everywhere else, we weight the regression by mileage opened in a given state-year. This produces results that are representative of an average mile of Interstate, rather than of an average state.²⁹

Our covariates include two types of controls. First, we include segment-specific controls for geography (both human and physical), denoted $\mathcal{G}$. Because these controls are a function of the specific miles completed, they vary over time. These geographic controls are measures of population density; topography; and wetlands, rivers, and other waters. Second, we include state fixed effects, I_s , which control for any statewide features. In Appendix Table A2, we add other covariates.

To assess whether the increase in spending per mile is statistically significant, we begin by estimating equation (1) without controls, and we present the coefficients β_1 in Table 2. Column (1) shows results without no controls, and column (2), which we refer to as our “baseline” model, adds state fixed effects. Column (3) adds our geographic controls to column (1), while column (4) includes both geographic controls and state fixed effects.

Figure 2 shows the period coefficients from this baseline model with the lighter line. These β_1 coefficients report any difference by period in millions spent per mile relative to the period 1958-63. The period coefficients show no statistically significant difference from this period to the next period, 1964-70. However, by the early 1970s, a mile cost \$4.0 million dollars more to construct than it did in the first period, and \$8.4 million more by the late 1970s. In the 1980s and early 1990s, per mile expenditures rose even further. These per-period increases are estimated precisely ($p < 0.05$ in the early 1970s and $p < 0.01$ after that).

²⁹ Of course, if the parameter of interest is what affects *state-level* spending, then it would make sense to not weight and instead to treat each state as a different policy experiment.

The darker line in Figure 2 (and column 4 in Table 2) shows our “Baseline + Geographic Controls” model, reporting the coefficients β_1 with the addition of the geographic controls listed in Table 2. Despite the addition of these controls, the post-1970 period coefficients are statistically indistinguishable. All coefficients from the early 1970s onward are statistically significant at the 1 percent level, and Figure 2’s purple region shows the confidence interval for these coefficients. The timing of the measured cost increase remains: flat costs through the late 1960s and then a large increase after that. Although the period indicators are little changed by the inclusion of geographic covariates, we do find a relationship between spending per mile and these geographic determinants. These results, shown in column (3) of Table 2, suggest that there is substantial signal in our matched spending and mileage openings. The first additional thousand people per square mile of population density is associated with an additional \$9.4 million dollars in per mile expenditures.³⁰ Highway segments crossing a greater share of wetlands, rivers, and other waters as a percentage of the segment’s length are associated with higher spending per mile, as are segments crossing steeper terrain. With state fixed effects added in column (4), we no longer have the power to measure the effects of wetlands, rivers, and other waters and topography, and those coefficients lose their significance.

Having demonstrated an increase in spending per mile starting in the 1970s, we turn to evaluating whether there are observable Interstate construction choices correlated with this increase. Specifically, we concentrate on attributes of highway miles that are within the scope of state choice, that are observable, and that may be correlated with higher spending: time from beginning to end of construction, the wiggleness of highway miles, and the quantity of Interstate capital employed via ramps and bridges. Figure 3 shows the time path of these four attributes of highway miles. Broadly, we see increases in three of the four measures, though some show more variation over time than others.

The top right panel shows the average wiggleness of a highway mile by year. We calculate this value as the ratio of the true length of each of our observed one-mile segments divided by the straight, as-a-crow-flies distance between the segment’s endpoints. The minimum value for this measure is one, which is the value for entirely straight segments. The curvier a highway segment, the larger the ratio. State decision makers could make highways curvier to

³⁰ Note that this measure is of population density when the highway is built, so it adjusts over time.

route around obstacles—physical, environmental, or political. Like the timing of the increase in spending per mile, highway segments become substantially wigglier after the early 1970s.

The top left panel shows average completion time for segments, which we measure as the number of years that pass between the time construction starts and ends for each segment. This figure has a different x-axis—year that construction began, not opened—from the rest of the figures in the paper. This modification addresses the concern that miles *opened* later will, all else equal, be the ones that took longer complete. Also, the data series starts later because so much data (over 90%) are missing in earlier years. Unlike the other three measures, this one declines at the end, showing that miles that started later were completed faster.

The final charts show two measures of the 2016 capital intensity of the Interstate system by year the segments were opened. The panel on the bottom left shows the ratio of miles of ramps to miles of Interstate in each year. Ramps connect an Interstate to another highway or road (e.g., off-ramps and on-ramps) (FHWA 2016b). The panel on the bottom right gives the ratio of bridge or overpass mileage to Interstate mileage. The definition of a bridge is broad – any structure that goes over something else and is at least 20 feet long.

These two measures both increase over time. The intensity of use of ramps has a U-shaped pattern over time, with high capital intensity in the early years of the system, followed by a decline roughly through 1975 and increases thereafter. In contrast, the use of bridges is roughly flat through the early 1970s and then turns upward, continuing to generally increase in capital intensity per mile for the remainder of the period.

We now turn to variation in spending per mile across states, documenting the second stylized fact of substantial variation in spending across states. The left side of Figure 4 shows total spending per mile in each state (millions of 2016 USD), and colors states by their census region. North Dakota spends the least per mile at an average of \$3.6 million over the entire period. By contrast, Delaware spends the most per mile, averaging just over \$50 million spent. In other words, Delaware spends more than ten times what North Dakota does constructing a mile of Interstate.

This cross-state variation is dampened but still large when we add the geographic covariates in Equation (1). We produce the mile-weighted average state residuals from column (3) of Table 1, which result from controlling for geographic features and time effects. We scale the minimum residual to 0. The right panel of Figure 4 reports these average adjusted residuals,

which give states' average costs (relative to the least costly state) unexplained by geographic covariates.

At the expensive end of the distribution, the 75th percentile state of Michigan spent just over \$20.7 million (2016 USD) more per mile than the state spending the least per mile after controlling for geography (Delaware). By contrast, at the inexpensive end, the 25th percentile state of New York spent just over \$17.8 million more per mile relative to Delaware. Furthermore, there is a difference of roughly \$34 million spent per mile between the states spending the most (New Jersey) and least (Delaware) per mile after controlling for geography.³¹ Thus, even with geographic controls, there are significant unexplained differences in spending per mile across states.

Figure 5 presents the quintiles of this distribution on a map, which divides spending per mile after controlling for geography (the right column of values in Table 4) into quintiles. The most expensive quintile is the darkest, and the least expensive quintile is the lightest. (Appendix Figure A3 is an analogous map without controlling for geographic characteristics.) In general, Western and Southern states construct more inexpensively; most Northeastern states are in the top half of the spending per mile distribution. That said, there remains considerable variation even within region. This variation is consistent with the large and much-studied variation in health care costs across states (Anderson et al. 2003, Skinner and Fisher 2010, Cooper et al. 2018).

Finally, Figure 6 shows, for each state, spending per mile in the pre- and post-1970 periods—roughly dividing the data before and after costs increase—after controlling for geographic features.³² In particular, we take the residuals, after controlling for geographic characteristics, from column (3) of Table 2 averaged by state across years in the pre- and post-1970 period. (Appendix Figure A4 presents an analogous figure without controlling for geographic characteristics.) The arrow begins with 1958-1970 average residual spending per mile and ends with the 1971-1993 average residual. We order states by the pre-1970 average residual. The figure shows a couple things. First, all but six states required more dollars to build a highway mile post-1975 than the pre-1975.³³ Second, there is a dramatic increase in the

³¹ We estimate a correlation of 0.1762 between a state's all-time spending per mile and its all-time spending per mile net of geographic controls.

³² In our data, 65.07% of the miles are built through 1970 and 35.93% after 1970.

³³ These states are New Jersey, Louisiana, Maine, Idaho, Montana, and North Carolina.

variance of costs over time, with all states but four within \$8 million per mile of each other in the pre-1970 period but considerably more variation later. The variance of costs is 42.9 pre-1970 and 112.6 post-1970, a little over a 2.5-fold increase.

5. Explanations: What Might Drive Infrastructure Costs?

Having shown a large increase across time and large variation across states in per mile Interstate spending, we now turn to potential explanations for these patterns. We focus on the change over time, but also briefly describe cross-sectional differences at the end. We begin by describing five hypotheses that appear largely inconsistent with the data. We then turn to two explanations that do appear particularly consistent: increasing citizen voice in government decision-making and increasing use of labor. We then outline other possible explanations, for which evidence is more limited. While we aim to shed light on causal drivers, we view the work in this section as suggestive and predominantly correlational, assessing how well different explanations fit the data.

A. Increase in Costs Over Time

1. Hypotheses that Do Not Appear to Be Primary Drivers of Costs

Five explanations of the increase in spending per mile appear largely inconsistent with our data. We review each in turn.

Geographically difficult segments built later. First, state transportation agencies may delay the construction of geographically difficult segments. This would yield an observed increase in spending per mile, but with no changes in underlying demand or supply factors. However, as we have shown in Figure 2, the addition of controls for the most obvious geographic drivers of cost has little impact on the value or pattern of the trend over time. Appendix Table A2 shows that this result is robust to very flexible functions of all the geographic covariates.

Labor and material input prices. Second, the most straightforward explanation for the increase in spending per mile is an increase in labor or material input prices, such as a sustained increase in the price of concrete. Figure 7 indexes spending per mile (as shown in Figure 1), as

well as construction labor and materials prices,³⁴ to 100 in 1965. We use the Bureau of Labor Statistics' hourly construction wages to measure construction labor prices and its Producer Price Index to measure materials prices (Carter et al. 2006, Bureau of Labor Statistics 2017). The difference in the temporal pattern between our measure and these price indices is striking. The figure shows a small increase in spending per mile by the end of the 1960s, commensurate with increases in labor prices. Through most of the period after, spending per mile increases, while labor and materials prices are unchanged in real terms at the end of the period. Thus, the explanation of increasing labor and material prices—at least as measured here—cannot explain the increase in spending per mile. Furthermore, because the price of labor is roughly flat, a Baumol cost disease-type explanation, in which high priced labor accounts for an increasing share of expenditures, is not consistent with the data (Baumol and Bowen 1965).

Note as well that the divergence between the price of the underlying components of highway construction – labor and materials – and overall highway spending begins in the early 1970s, consistent with when Interstate spending per mile begins its especially dramatic upward trend. This divergence suggests that changes in labor law (e.g., prevailing wage laws like Davis Bacon) that increased unit prices are also unlikely to be drivers of increasing costs.

The divergence between input prices and final spending per mile may also speak to a question analogous to the important debate in health economics about whether prices or quantities drive high US health care spending per patient. Many in health economics argue that high American healthcare spending is driven by high prices, noting that along most measures of aggregate utilization (“quantity”)—per capita physician visits, per capita hospital days, per capita acute beds, etc.—the United States is actually *below* the OECD median despite having the highest per capita OECD spending (Anderson et al. 2003). In the same way that these low quantities suggest that high prices drive higher US health care spending per patient, the absence of increases in input prices over time suggests that high quantities of inputs drive higher US infrastructure spending per mile of highway.³⁵ Alternatively, it may be that the “quality” of an

³⁴ We measure material prices as the equally weighted sum of prices for concrete ingredients and related products, construction machinery and equipment, construction sand, gravel and crushed stone, and paving mixtures and blocks. It is, of course, possible that we are missing important input prices that do increase over time.

³⁵ While prices seem to drive higher US healthcare spending when compared with the rest of the world, quantity effects help drive domestic regional variation, especially in Medicare (Skinner 2010).

Interstate mile increases over time, requiring more inputs such as sound barriers or longer bridges. [we'll want to put in Leah's new figure and info, once we know what's in it]

Right of way acquisition and planning costs. A third explanation also appears to be insufficient as a major explanation: an increase in right-of-way acquisition or planning costs (Garnett 2006). To evaluate this explanation, we digitized additional data from 1961 to 1984³⁶ that divide expenditures by type: construction versus preliminary engineering and right of way. As Figure 8 shows, the share of spending on right of way and planning costs is fairly small. These costs are less than 18 percent of expenditures over the entire period and never exceed 25 percent in any given year. Furthermore, this share declines, rather than increases, over time. Thus, even if one would have expected even larger declines in this share as projects in later stages disproportionately moved from planning and right-of-way acquisition into the construction phase, the dominant cost of building the Interstates was construction itself, not planning or acquiring rights of way. These data also suggest that changes in eminent domain law do not make a large, direct contribution to the increase in spending per mile, though they could indirectly impact construction costs by leading to more expensive routes. Overall, while right of way acquisition and planning costs contribute to rising construction costs, since their share drops only modestly over time as costs go up, spending is overwhelmingly on the construction itself, suggesting that major explanations must focus on that.

Time-invariant features. Fourth, anything constant over time cannot alone explain the increase in spending per mile. For example, some authors have suggested that the high cost of infrastructure in the United States may be partly due to the strictures in common law, which provide more protection for property owners (Gordon and Schleicher 2015). In theory, these protections allow individuals and small groups to slow down development with costly lawsuits and other legal challenges. Our data are inconsistent with the idea that something about the US common law tradition alone yields increased spending per mile. While it may be true that it is more expensive to build in common law countries relative to civil law ones, this is not a sufficient explanation for our particular case of increasing spending per mile: the United States is and was a common law country, and things that do not change should not cause large changes in costs. However, of course, the common law could have interacted in important ways with other trends to yield cost increases.

³⁶ Annual data are not available for the entire period. However, other statistics show that ROW expenditures were only 12.6% of the spending on building the Interstates through 1991 (the vast majority of the spending). Similarly, PE, planning, and research spending, along with “miscellaneous” spending, amount to only 8.0% of the costs of building through 1991. Weingroff, Richard. 2017. “The Dwight D. Eisenhower System of Interstate and Defense Highways: Summary of the Interstate Cost Estimate (ICE) Process.” *Federal Highway Administration*. <https://www.fhwa.dot.gov/highwayhistory/data/page03.cfm>. These statistics do not adjust for inflation though—and these expenditures were likely disproportionately done in early years, so inflation-adjusted shares are likely higher.

Federal Interstate standards. Finally, with the exception of increased capacity requirements,³⁷ there were no large changes in federal Interstate construction standards that might increase spending per mile. After an extensive search, we are unaware of any other substantial changes in design standards that could have led to substantially increasing costs over time,³⁸ though we cannot rule out the possibility that many small changes of which we are unaware aggregated to a substantial impact. To be clear, we are not asserting that highways have been built the same way over time (quite the contrary), but rather that such changes were not federally mandated by Interstate planners.

2. Regression Evidence

If changing geography, materials and labor prices, land acquisition and planning costs, unchanging characteristics of US infrastructure spending, and federal Interstate standards do not generate the spending patterns we observe, what might? To help answer that question, we both further interpret the data presented in Section 4 and produce regression analysis of policy variables to measure their relationship with costs. In particular, following Chetty et al. (2014), Finkelstein et al. (2016), and others, we produce bivariate regressions on the correlation between the policy variables and costs net-of-geography. We do this in two steps. First, to measure the increase in costs net-of-geography, we take the average residuals by state from column (3) of Table 2 and compare them before and after 1970. Second, we measure the correlation at the state level between these cost increases and policy variables, with the following regression:

$$cost_residual_{post-1970,s} - cost_residual_{pre-1970,s} = \alpha_0 + \alpha_1 policy_s + \varepsilon_s \quad (2)$$

³⁷ The one exception is increasing capacity requirements over time. (See the discussion in Section 2 of increased capacity and lane width requirements.) However, we can directly assess the impact of this change by adding a control variable, albeit an imperfect one as it measures lanes as of 2016, not as of the date of construction. Nevertheless, since lane Interstate widenings are fairly rare, we view this as a good proxy.

³⁸ Changes to Interstate highway design standards included (1) increased specificity about the paving and design of highway shoulders between 1967 and 1991; (2) the reduction in median width in rural areas from 16 feet wide to 10 feet wide; and (3) a minimum 20-year future lifespan for bridges to remain in service. Compare “Geometric Design Standards for the National System of Interstate and Defense Highways,” AASHO, 1967 (codified via 39 Fed. Reg. 35145 (1974) at 23 U.S.C. § 625.3(a)(2) (1975)) [hereinafter, DS-2] to DS-4. Additionally, (4) AASHO introduced pavement design standards in 1961, following the AASHO road test. See “Interim Guide for the Design of Flexible Pavement Structures,” AASHO, 1961. Notably, much of the interstate system’s design standards have remained constant over time. Compare DS-2 to DS-4.

All variables are divided by their standard deviations so that α_1 can be interpreted as a correlation.

We assess five policy areas that have been discussed as possible cost drivers and that also have data fairly readily available. While not suited for precise causal identification, our results suggest two plausible explanations. First, our results are consistent with increasing “citizen voice” in the development process in the late 1960s and early 1970s being a contributing cost driver. Second, proxies for increased labor use are correlated with cost increases. We discuss each explanation in turn. We also consider other explanations: government fragmentation, income, and government quality. Figure 9 shows the correlations (α_1 in equation (2)) between the policy variables, grouped by type, and cost increases. The dot shows the point estimate, and the bars show the 95% confidence interval.

[[[

Regardless of specification – even those with state and period fixed effects – the R^2 is always less than one half. In other words, our observable covariates cannot explain a large portion of the variation in miles produced per dollar spent.

As a preliminary matter, we make two notes. First, it is reassuring that inclusion of these variables considerably shrinks the magnitude of the period fixed effects in later years. From column (3) of Table 2, without the additional variables, to column (1) of Table 3, with them, the average coefficient on the period indicators after 1975 drops slightly less than 20 percent. This fact suggests that these variables do have some explanatory power for the increase in costs over time.]]]

i. Citizen Voice

The first explanation (or, group of explanations) consistent with our data is the rise of “citizen voice” in democratic and development processes (Altshuler and Luberoff 2003, p. 22). Specifically, in the late 1960s and early 1970s, a combination of social movements, legislation, and judicial doctrine significantly expanded the opportunity for citizen involvement in the process of infrastructure development.

This increase in citizen voice started in the late 1960s, gaining teeth with the Supreme Court’s landmark 1971 case, *Citizens to Protect Overton Park v. Volpe*.³⁹ This case established extensive judicial review over executive agencies by lessening the scope of decisions “committed to agency discretion” and thereby ensured citizen ability to sue on the basis of a variety of pieces of legislation. Those pieces of legislation include the National Environmental Policy Act of 1970 (requiring environmental impact reviews for projects with significant federal funding), the National Historic Preservation Act of 1966 (preventing development on national historic sites), the 1973 Endangered Species Act, the 1972 Clean Water Act protecting wetlands,⁴⁰ and other federal legislation making it more difficult to develop on public lands. Many states also passed their own statutes on environmental review. This legislation also roughly coincides with the founding of public interest environmental law organizations (Sabin 2015), which helped enhance citizen voice, as well as a wave of unrest about the construction of the Interstates (Swift 2011). During roughly the same period, there was a rise in the organization and political power of homeowners sensitive to fluctuations in the value of their largest asset and hence increasingly vocal in restricting development of all sorts, including infrastructure (Fischel 2001, Glaeser and Ponzetto 2017).

There are multiple reasons that these changes could increase the cost of building infrastructure. The first is the cost of the environmental review itself: environmental review statutes require that projects involving significant government funds conduct environmental reviews. Litigation is costly too. However, as Figure 8 shows, the costs of Interstate highway projects are overwhelmingly in the form of construction itself, so we view it as unlikely that this mechanism is a major contributor to costs. Second, the environmental review statutes may require more expensive routes or methods of construction to limit environmental impacts and otherwise respond to citizen demands. As well, environmental review statutes allow many potentially affected parties to sue to stop or delay projects. As a result, projects may not only be delayed but may also take more expensive routes or use other more expensive methods to satisfy recalcitrant opponents empowered by statutes. We view this as the most likely mechanism of

³⁹ 401 U.S. 402.

⁴⁰ The Army Corps of Engineers must affirmatively grant a permit to projects with the potential to harm wetlands under Section 404 of the Clean Water Act. The Corps often requires projects to mitigate any wetland losses. The Corps’ jurisdiction has gradually expanded to cover almost all bodies of water in the United States.

increased spending: citizen voice leads to more expensive routes and structures to respond to local concerns.

Several pieces of evidence are consistent with our posited relationship between citizen voice and construction costs. First is the regression evidence. Several proxies of citizen voice are strongly correlated with cost increases. The most strongly correlated variable is population density (both within the citizen voice category and also across all variables considered), which could be a proxy for citizen voice because with greater population densities, there are more people to voice concerns. The Wharton Land Use index, a 2006 measure of how restrictive development is, is also significantly correlated. An indicator for states that have significant state environmental impact review statutes—indicative of states interested in more citizen involvement even if the statutes did not specifically lead to it for Interstates—is also correlated. A measure of the number of land use cases, which has high standard errors, does not have a statistically significant correlation.

Local housing prices also have a large and significant (at the 10% level) correlation. This is consistent with the rise of homeowner power, in which homeowner demands become a larger determinant in local government decisions (Fischel 2001). Fischel argues that wealthier homeowners are more demanding, a relationship that could drive the correlation between higher spending per mile and higher home values. As suggested earlier, though, since land costs are a relatively small share of total costs, we believe that the mechanism here is not that the land itself is expensive, but rather that high house prices are correlated with politics driving higher spending. Across these variables, magnitudes are similar, though standard errors are somewhat larger (in some cases making coefficients insignificant), when controlling for region (see Appendix Figure A5 and Appendix Table A4).

To help understand the importance of citizen voice, we take the most strongly correlated variable, population density, and perform additional analysis. In column (6) of Table 3, we add density interacted with an indicator for being after 1970 to column (4) of Table 2, which is reproduced as column (1) in Table 3. The coefficient on the interaction term is large and strongly significant. Furthermore, the coefficients on the year bins decline substantially. The magnitude of the post-1970 year bin coefficients drops by 44% on average. This result means that the increased relationship between density and costs over time can alone explain a significant

portion of the increased costs. [mention that doesn't show up as significant in change column in altenraitive specification]

In addition to the evidence on cross-state correlations of cost increases, several other pieces of evidence are consistent with an important role for citizen voice. First, the increase in spending per mile begins in the early 1970s, roughly coinciding with when the laws, judicial doctrines, and social movements increasing citizen voice began to come into full effect. Second, the Interstate attributes—wiggleness, bridges, and ramps⁴¹—discussed in Section 4, which could reflect mechanisms by which citizen voice increases costs, also show similar time trends. In particular, we show that, especially for miles from the early 1970s onward, miles were more frequently associated with auxiliary structures and became wigglier. This behavior can (though needn't necessarily) be interpreted as a response to local demands, either to mitigate impacts via bridges and elevated highways, or to increase commerce, such as with more frequent off-ramps. Wiggleness is plausibly consistent with a planning process more sensitive to citizen opposition and environmental protection, and one more strongly characterized by the costs that sensitivity potentially entails.

The regression evidence in Table 3 shows that these trends are associated with higher spending per mile. An additional structure per mile of Interstate is associated with an increase in spending of \$17.53 million (column (2)). The coefficient on wiggleness suggests that an increase equivalent to the average change in wiggleness we observe from the 1960s to the 1980s – a change of about 0.01 (which is also the variable's standard deviation) – is associated with an increase in spending of \$9.71 million (column (3)), which is significant at the 10% level. We interpret the result as likely suggesting that projects *associated* with wigglier highways may have encountered resistance that both led to less direct routes and also more expensive construction, rather than that wiggly roads are more expensive to construct on their own. Though both estimates are somewhat smaller (and wiggleness is no longer significant) in column (5), which includes the variables together, this evidence is consistent with an argument that citizen voice (or some other mechanism) leads to more heavily engineered highways, driving up costs.⁴²

⁴¹ One may be concerned that the fact that more highways may intersect over time as more highways get built would lead to more ramp construction over time, driving up costs. That may very well be true. However, we provide data on ramps as of 2016, not as of when the highways were built. So this trend would not show up in our data. But there could be more bridges over time for this reason.

⁴² In this light, our regression evidence that a longer time to complete is associated with *more* highway production may at first be puzzling. (Note that we only have this data for 51.9 percent of segments across all years.) We find

Overall, the evidence tells a story largely consistent with the idea that highway construction became increasingly responsive to citizen voice over time, specifically in ways that increased cost. However, we emphasize that, though several other explanations appear inconsistent with the data, this explanation is merely *consistent* with the data—and is not necessarily an important cause, nor a cause at all. Furthermore, we say nothing here about the benefits of citizen voice, even if they are causally related to rising costs. We speak only to the costs.]]

Finally, to illustrate how the rise of citizen voice could drive costs, we discuss the construction in Detroit's northern suburbs of I-696, a 28-mile stretch of Interstate. It was built in three legs of similar lengths, all of which share a similar geography (Bureau of Public Roads 1955, p. 41; Hundley 1989).⁴³ The earlier two legs faced little resistance and cost far less than the latest leg, which faced significant resistance. The first leg was completed in 1964 at a cost of \$13 million per mile (2016 USD) (Brown 1990, Hundley 1989). The second leg was completed in 1979 at a cost of \$48 million per mile (2016 USD) (Brown 1990).⁴⁴ The latest leg began planning in 1964—the same time as the second leg—and was completed a quarter century later, in 1989. It cost \$86 million per mile (2016 USD), roughly seven times the first leg and twice the second leg. This final leg disrupted a Jewish community around Oak Park, leading to years of community opposition (Center for Urban Transportation Research 1998).

Multiple strands of the rise of citizen voice are present in this story. Given the prohibition in Judaic law on driving on the weekly Sabbath, the proposed 8-lane highway through the neighborhood would significantly disrupt community members' lives. The community organized and lobbied, and in response, local governments opposed the project on their behalf for the remainder of the 1960s.

that an extra year to complete correlates with a decrease in per mile costs of \$1.11 million. Our hypothesis was that segments that took longer to complete might be correlated with more difficult construction, reducing highway production. However, there is a countervailing factor owing to measurement error: if a mile takes longer to complete, we capture less of total spending in our data, driving down measured spending per mile and therefore the coefficient on time to complete. One plausible interpretation of this result is that the measurement error effect dominates.

⁴³ Furthermore, all three legs were built through fairly dense areas, passing through tracts with population densities well above 1,500 people per square mile. That said, the 1960 population density of the western leg (1,657 people per square mile) was less than that of the middle (5,294 people per square mile) and eastern (4,107 people per square mile) legs.

⁴⁴ Data are from Baum-Snow (2007). Construction began in 1969-71

Homeowners exerted especial power through a peculiarity of Michigan state law, which stipulated that the routes of Interstates running through cities were subject to city approval.⁴⁵ Between the eight cities whose approval was required for the middle leg, the situation grew so tense that then-Governor George Romney stepped in: “[he] locked squabbling officials in a local community center overnight, and told them he would not let them out until they came to agreement” (Woodford 1972, p. 54, Schmidt 1989). Local residents also used the recently enacted National Environmental Policy Act as a tool for highway opposition. According to the *New York Times*, in the 1970s, “foes began using new Federal environmental rules to oppose the road, arguing that it would wreak untold damage” (Schmidt 1989).⁴⁶ In addition, in the late 1980s, the state was required to replace 6.5 acres of wetland with 11 new acres (Woodford 1972 p. 54, Schmidt 1989, Associated Press 1987).

In the end, the final compromise in 1981 that allowed the highway to go forward required the state to 1) hire a rabbi to consult on the project, 2) depress the entirety of the middle leg, 3) build three 700ft long plazas above the depressed highway, 4) install noise walls along most of the route (they had already agreed to do this near the zoo, but expanded the reach), and 5) install a network of pedestrian paths (Schmidt 1989).⁴⁷ Apart from the rabbi, these features are shown in Appendix Figure A6.

ii. Increased Use of Labor

While Figure 7 above showed that the price of construction labor has been fairly flat over time, Interstate construction could have used greater quantities of labor over time—a variable that we do not observe in our data but that would be a valuable piece of information to uncover with further study. Some groups say that “featherbedding,” or hiring more workers than necessary for a project, often because of union work rules, is an important cost driver (Belman et al. 2007). Part of the reason that unions can demand such work rules is that “project labor agreements” (PLAs) signed by states require union labor. It is less clear why there would be more use of labor over time because of PLAs at the same time that the power of unions has, if

⁴⁵ United States Senate Committee on Public Works Subcommittee on Roads. 1970. *Report on the Status of the Federal-Aid Highway Program Hearing, Ninety-First Congress, Second Session, April 15, 1970*. United States Government Printing Office. Washington, D.C. p. 93.

⁴⁶ Furthermore, along I-696 as a whole, a reported 40% of homeowners challenged the state-paid relocation packages in court (Hundley 1989).

⁴⁷ *Id.*

anything, waned. One possibility is that, consistent with some evidence, PLAs became more commonly used over this time period (Belman et al. 2007, p. 10), partly driven by poorer economic conditions than those that existed in the 1960s, when employment—especially employment in highway construction—was abundant.

To assess the potential importance of employing more labor, we measure the correlation of per mile spending with three primary variables: unionization rates, the presence of “right to work” laws making unionization more difficult, and the average share voting Democrat in Presidential campaigns over our time period as a proxy of the state’s political leanings and its desire to hire more labor. Of course, this Democratic voting variable could proxy for many things other than hiring labor, including citizen voice.⁴⁸ We also include a fourth variable as a kind of placebo that we do not expect to have an impact: the presence of prevailing wage laws requiring that construction projects pay higher wage rates. Since labor prices do not appear to have gone up, we do not expect this variable to be strongly correlated with cost increases.

Results are consistent with a role for increased use of labor. The unionization rate is significantly correlated with cost increases, and the presence of right to work laws are correlated at the 10% significance level. The Democratic vote share is also significantly correlated.⁴⁹ Our placebo—the presence of prevailing wage laws—is, as expected, not significant. The Democratic vote share and share unionized remain significant after controlling for regions (Appendix Figure A5).

For these two explanations with the strongest correlations—citizen voice and labor use—we include representatives of both categories in regressions with change in costs after 1970 as the dependent variable, and including region fixed effects. Results are in Appendix Table A5. The coefficients generally stay significant, though they do not always do so.

iii. Government Fragmentation

Some researchers suggest that one reason infrastructure in the United States may be more expensive relative to Europe is the US system of fragmented governance, as different

⁴⁸ One citizen voice interpretation is that liberal places may have more activism, and thereby increase construction costs (Kahn 2011).

⁴⁹ We also repeat the calculation using the 2016 Democratic presidential vote share by state and the basic result remains the same: the variable is highly correlated with increased residual spending per mile (0.428) and is estimated precisely ($p < 0.01$).

governments may have difficulty efficiently cooperating with each other (Gillette 2001). While we cannot make a US-Europe comparison, we can assess whether greater fragmentation within the United States is associated with higher costs. In our regressions, the coefficient is not significant in the cross section. However, a separate question is whether states that had larger increases in government fragmentation also saw larger cost increases. To answer that question, we regress the cost increase on two variables: the pre-1970 average fragmentation and the change in fragmentation before and after 1970. The regression, reported along with analogous results for other variables in Appendix Table A6, has a large and positive coefficient on the change in government fragmentation ($\beta = 0.458$, $se = 0.202$), providing some supportive evidence of increased government fragmentation playing a role in cost increases.

iv. Income

In an explanation complementary to the citizen voice explanation, highway designs may simply be a luxury good: People were richer in the 1980s than in the 1960s, and thus demanded more expensive, less disruptive highways, which planners rationally obliged. Any increased income that does not vary across states is captured in our period effects. There is no significant correlation between income and cost increases in the cross section. Nor, as Appendix Table A6 shows, does states' increasing income predict cost increases. So we do not have evidence that income increases are important drivers of cost increases.

v. State Government Quality

We also examine various measures of government quality: an index of corruption based on a 1999 state-level survey of statehouse reporters (Boylan and Long 2003), the number of convictions of state officials per capita, and the state bond score.⁵⁰ None of these correlations are statistically significant, providing no evidence that government quality is an important driver of infrastructure cost increases.

⁵⁰ To quantify states' S&P bond rating, as a measure of the quality of their fiscal governance, we measure a AAA rated bond as 0, and then we measure each of the remaining ratings based on its average percent increase in the interest rate on a ten-year bond relative to that of an average AAA bond; so, for example, we add 16 for a year in which a state received a AA rating because its interest rate is 16 basis points higher than that for a AAA 10-year bond.

3. Other Potential Spending Drivers

There are many other potential explanations for which we do not have appropriate data. We list them briefly here.

Economies of scale. Over time, the US produced fewer Interstates, which may have reduced economies of scale and thereby yielded higher spending per mile. That said, the United States continued both building other highways and roads and refurbishing existing ones, likely blunting this effect.

Reduced competition. There is renewed interest in the effect of industrial concentration on a variety of areas of the economy, as well as evidence that builders may be able to manipulate their contracts in ways that increase spending,⁵¹ though whether this has changed over time remains an open question (Bajari and Ye 2003, Gil and Marion 2013, Mochtar and Arditi 2001, Miller 2014). We lack good data to assess this claim,⁵² but De Loecker, Eekhout, and Unger (2018) produced data on markup in the construction industry overall and find it little changed between the 1960s and 1980s.

Soft budget constraint/end of repeated game. As described in Section 2, the federal government reimbursed 90 percent of spending, and the amount of money available to states was not fixed. In the early years of the Interstate, state planners may have perceived a repeated game and behaved efficiently to induce future federal funding. However, as the end of the Interstate program neared, states may have believed that the federal government would complete the Interstate system regardless of their behavior. This is an example of the “soft budget constraint” problem (Kornai, 1980). Alternatively, norms of thriftiness could have broken down over time.

Procurement practices. Procurement practices may also play an important role in spending. For example, the federal government started requiring in 1968 that states accept the lowest-bidding contractor for highway construction projects.⁵³ With little penalty for going over budget, this could create bad incentives. Firms may under-bid in order to win a contract, and then

⁵¹ The way that bids typically work is that the state Departments of Transportation (DOTs) say that they will need given quantities of materials such as asphalt and guardrails. Bidders say how much they will charge per item, and the DOTs typically choose the lowest bidder. This creates an incentive for bidders to underbid on items that DOT is overestimating its usage of and overbid on items that DOT is underestimating its usage of. Bolotnyy and Vasserman (2019, p. 27) show that in fact firms do exactly that.

⁵² We considered using the Census of Construction Industries, but it does not have data that permit a calculation of the margins standard for understanding competitiveness.

⁵³ Federal-Aid Highways Act of 1968 § 22(c), Pub. L. 90-495, 82 Stat. 815, 827 (1968) (codified at 23 U.S.C. § 112(b)(1)).

subsequently go over budget.⁵⁴ And some criticize requests for proposals as overly prescriptive (McKinsey Global Institute 2013). Unfortunately, we were unable to find data on procurement practices. We think that this is fruitful area for future research.

B. Cross-Section

Though the focus of the analysis is understanding correlates of increased costs, we also document a remarkably wide dispersion in costs in the cross-section as well. Figure 10 has the analogous correlation coefficients for cross-sectional costs over the entire time period that the previous subsection had for the change in costs. Results are similar to those for the increase in costs, though with somewhat less significance. The Wharton Land Use Index and the state environmental review acts are significant under “citizen voice,” as is the unionization rate under the labor category. Otherwise, nothing is significant except for the corruption index (and nothing else in that category is significant).

6. Conclusion

The puzzles contained in our results raise important questions for future work: What precisely explains the enormous increase in costs over time that we have documented? And what explains the large variation in costs across states? Reams of papers are devoted to healthcare costs, but relatively little attention has been paid to the cost drivers of the 4% of GDP spent on infrastructure. We hope that our primarily descriptive contribution provides phenomena to understand, data to evaluate, and helpful initial forays into the critical task of explaining infrastructure spending.

As Congress considers a new infrastructure bill amid widespread criticism of the state of US infrastructure, and as the Administration attempts to reduce infrastructure costs, it is helpful to establish basic facts, of which we have strikingly few. This paper does so by studying the construction of the Interstate system, among the most extensive of US infrastructure assets. We show dramatic increases in per mile highway spending over time that are not explained by observable differences in geography. This increase appears inconsistent with some common explanations of infrastructure costs, such as increases in labor and materials costs, since these do

⁵⁴ We are told that this is precisely what happens at a large transit agency.

not exhibit the same time trend. Our data suggest that higher per mile spending is driven by quantities, not prices. As well, the results emphasize the importance of factors that have changed since the 1960s, rather than those, like the common law system, that have not.

We explore potential explanations for cost patterns that appear largely consistent with the data, especially the combination of social movements, legislation, and judicial doctrine leading to increased citizen voice. These findings on costs, while suggestive, are not causal. They also do not speak to potentially varying impacts of highway construction over space and time.

We also show that there is huge variation in costs across states that is not explained by observable differences in policy or in the geography of where the miles are built. This puzzling but striking unexplained residual resembles the large unexplained residual in health care spending across states and merits further investigation.

Our paper thus raises questions for future work on infrastructure costs: What causal factors explain the enormous increase in costs over time? And, what explains the variation in costs across states? A large literature explores these questions in healthcare, yet—despite some initial guesses here—we are just beginning to understand what even needs to be explained for infrastructure.

Much more work should be done to help understand the drivers of such an important part of the economy. This work could take many forms. For example, there are GIS data on the location of historic structures and endangered species. Did construction costs especially increase in areas with greater density of such features? Some contractors suggest that increased bureaucratization of the procurement and contract management process could explain rising per mile costs.⁵⁵ Perhaps analysis of data on state departments of transportation could provide evidence bearing on such a mechanism. These unexplained cost increases and the variation across states are enormous; understanding them may help us understand how to reduce costs or, depending upon the mechanism and the resulting benefits, whether those costs are worth bearing.

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⁵⁵ Conversation with Darryl Goodson, September 20, 2018.

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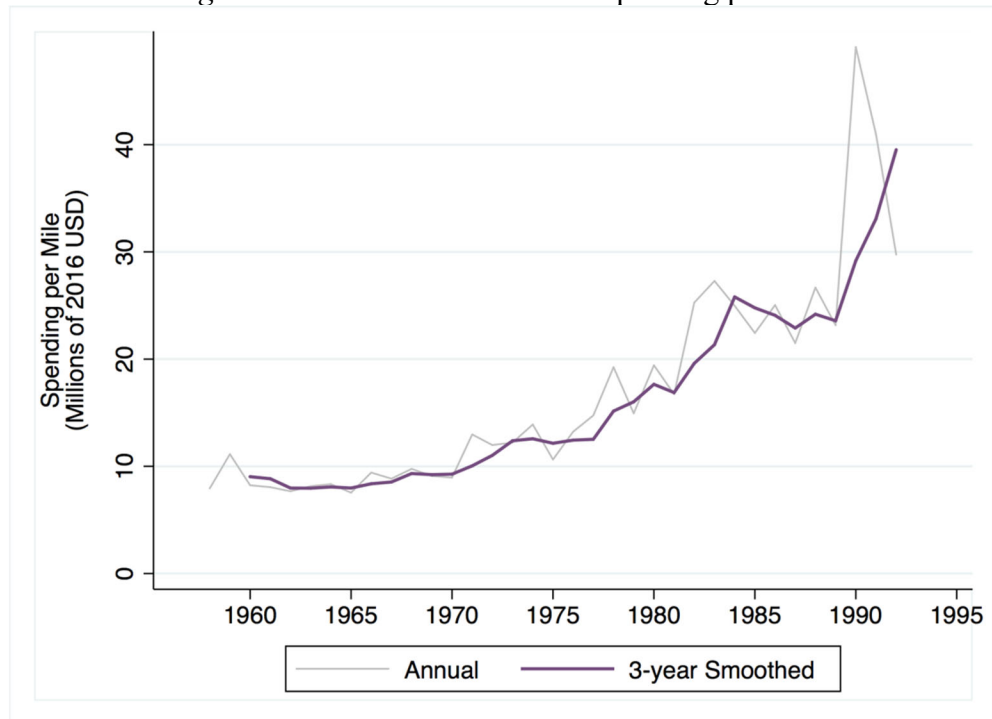
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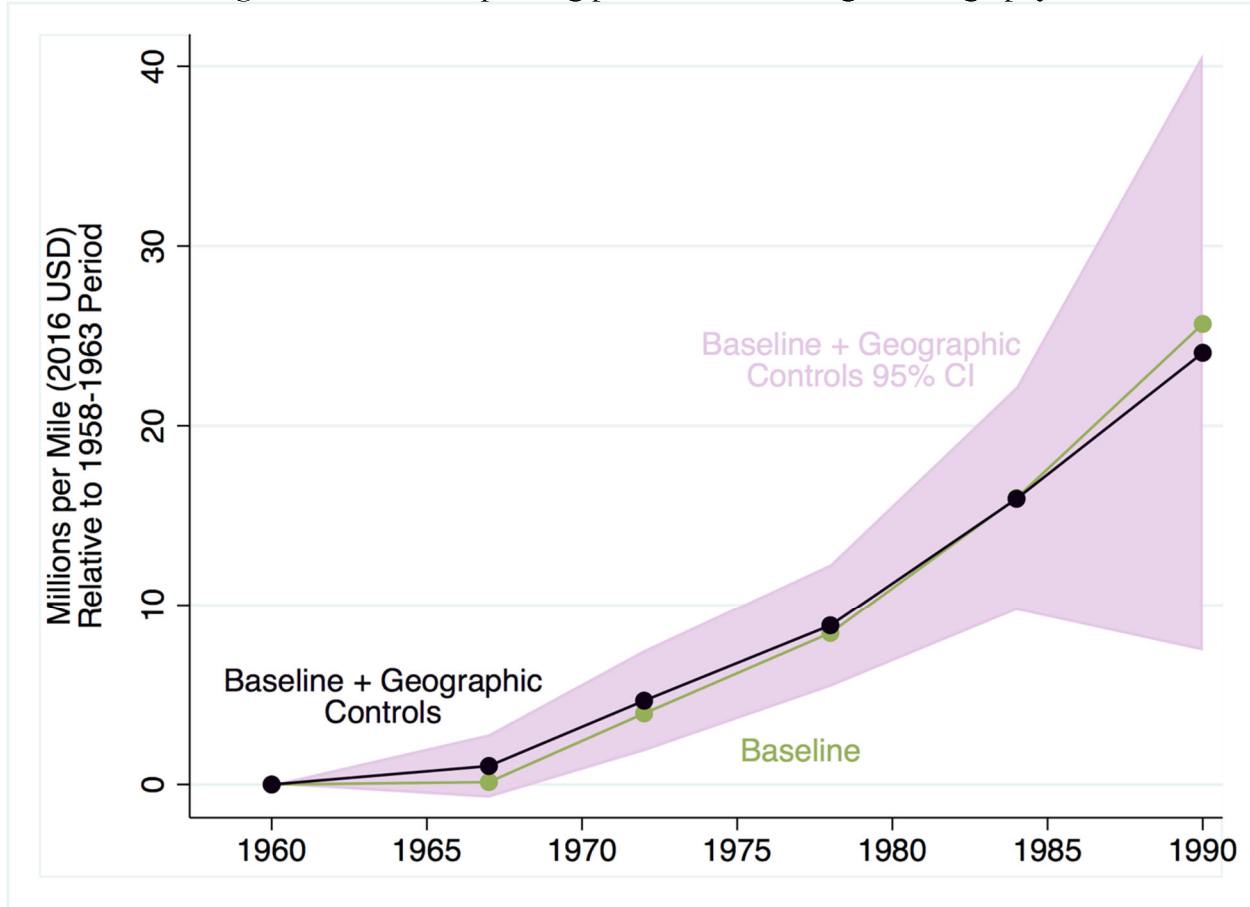
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<https://www.nap.edu/read/1101/chapter/9#78>.

Figure 1. Interstate Construction Spending per Mile



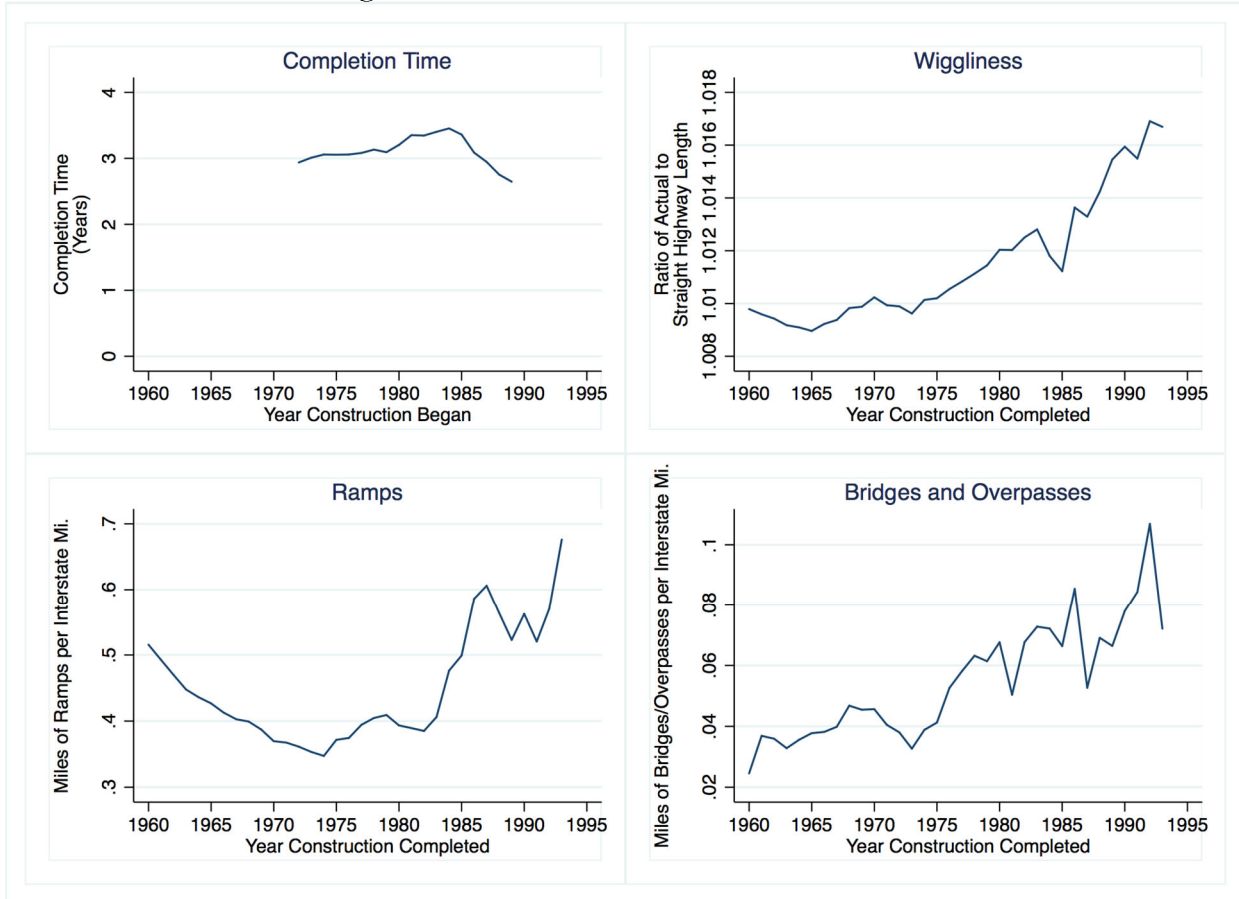
Notes: Calculated as the sum of US-wide spending over a period of time (a year or, if smoothed, 3 years), over the sum of new mileage in that same period.

Figure 2. Interstate Spending per Mile Controlling for Geography



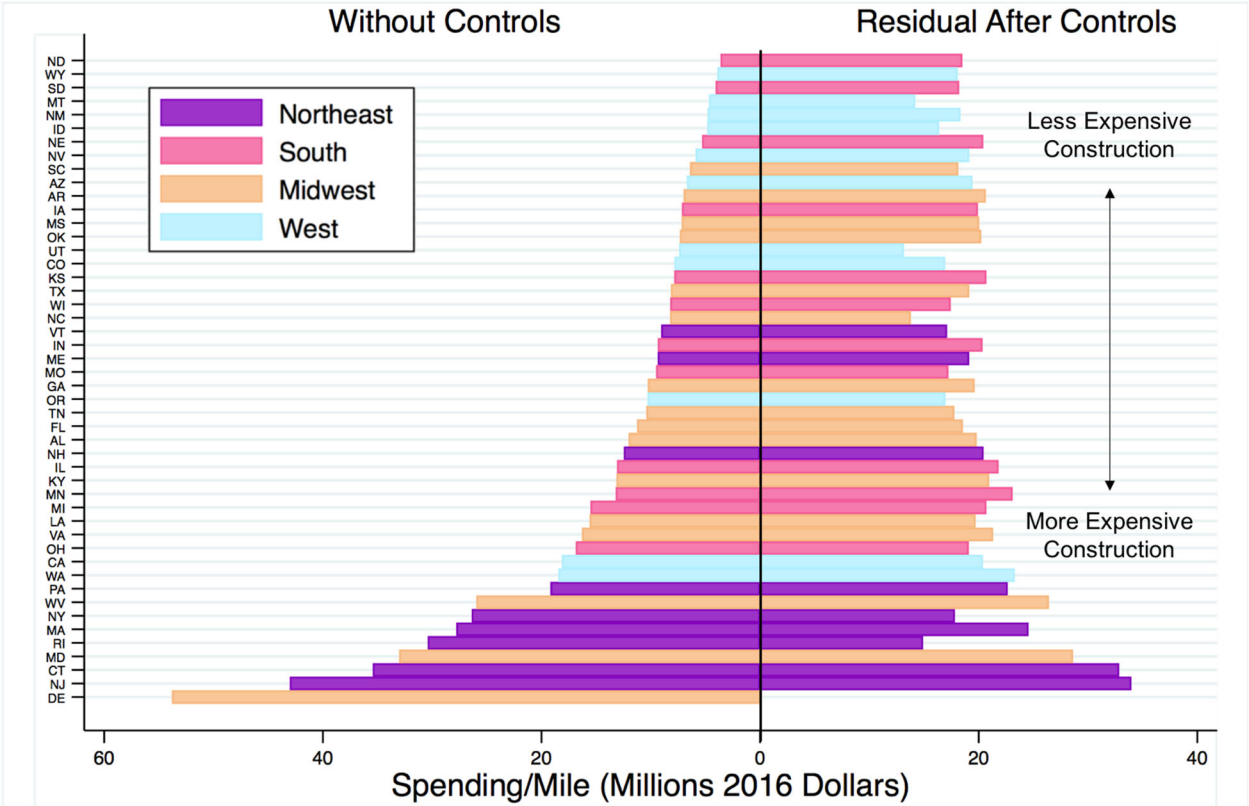
Notes: Points shown are the estimates for indicators for each time period in Table 2: “Baseline” is column (2) (only period effects and state fixed effects) and “Baseline + Geographic controls” is column (4) (period effects, state fixed effects, and geographic controls).

Figure 3. Time Trends in Interstate Attributes



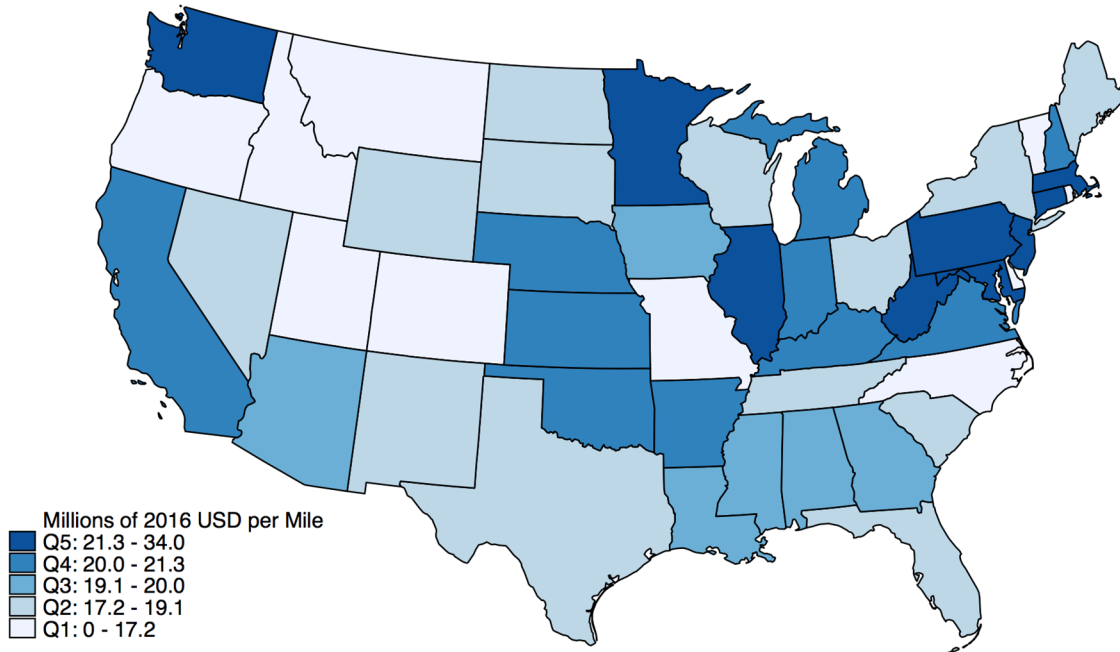
Notes: Completion time defined as the time elapsing between the start and end year of a segment's construction. For this variable, data are excluded before 1966 because of missing data. Wiggleness is the ratio of the 1-mile true length of a segment to the shorter distance connecting the segment's endpoints "as the crow flies." We measure the prevalence of ramps and bridges/overpasses by the number of miles of each associated, on average, with a mile of highway. All trends are smoothed over the current and previous four years; data pre-1960 is not shown as a result.

Figure 4. Interstate Spending per Mile by State



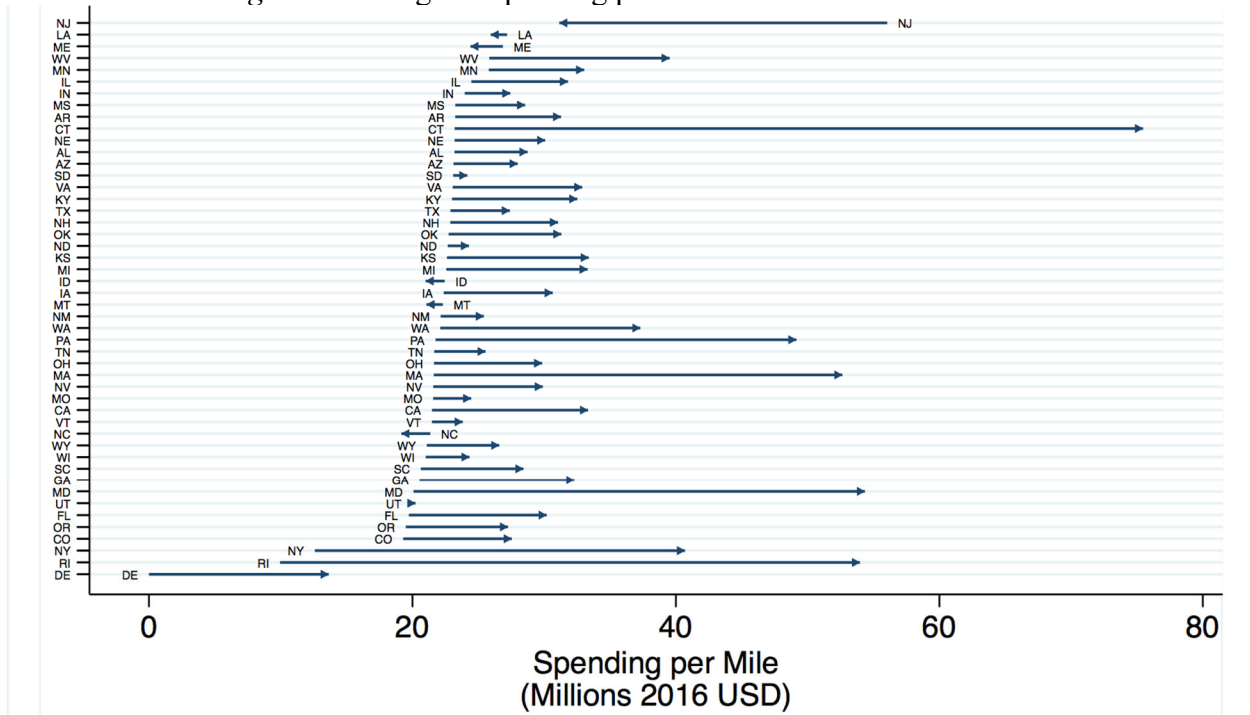
Notes: State-level values in the right column given as the miles-weighted average of residuals spending per mile after controlling for geography (from column (3) of Table 2). Residuals are scaled so the minimum average is 0.

Figure 5. Interstate Spending per Mile by State, After Controlling for Geography



Notes: Mapped values given as the weighted average of residuals from column (3) of Table 2. Residuals are scaled so that the minimum is 0.

Figure 6. Change in Spending per Mile: Pre-1970 vs. Post-1970



Notes: The pre-1970 and post-1970 values are given as the weighted average of residuals (respectively pre-1970 and post-1970) from column (3) of Table 2. Residuals are scaled so the minimum pre-1970 average is 0.

Figure 7. Spending per Mile and Highway Wage and Materials Prices

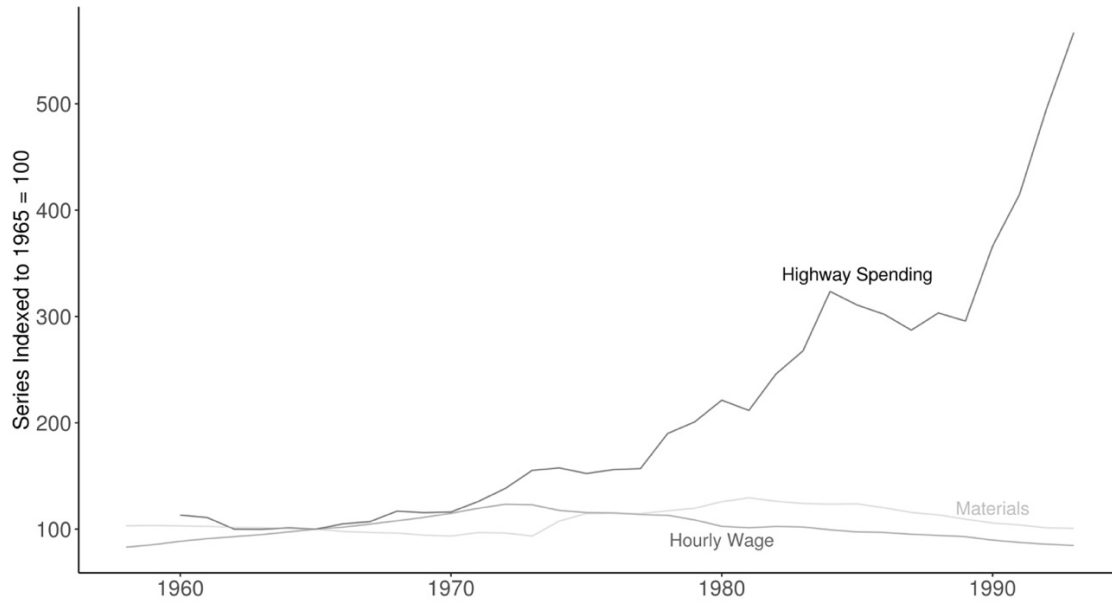
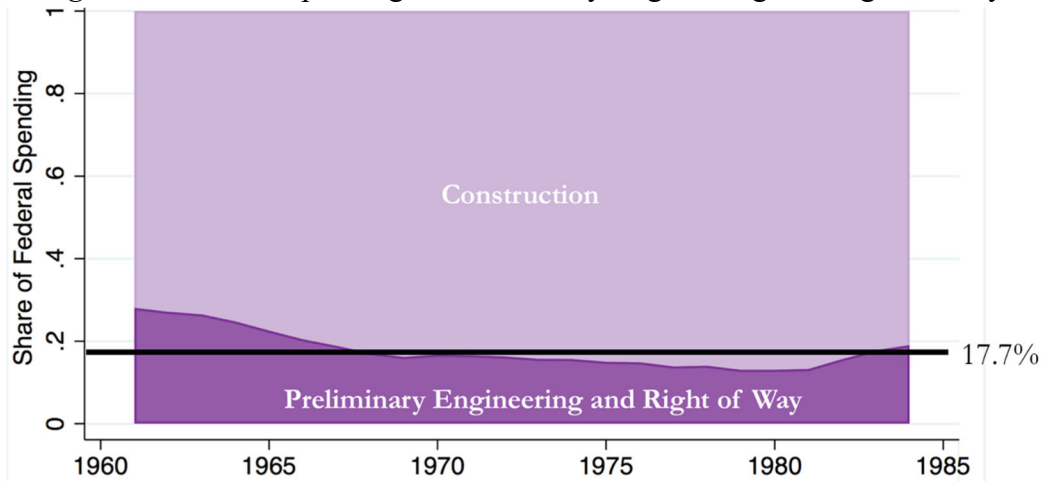
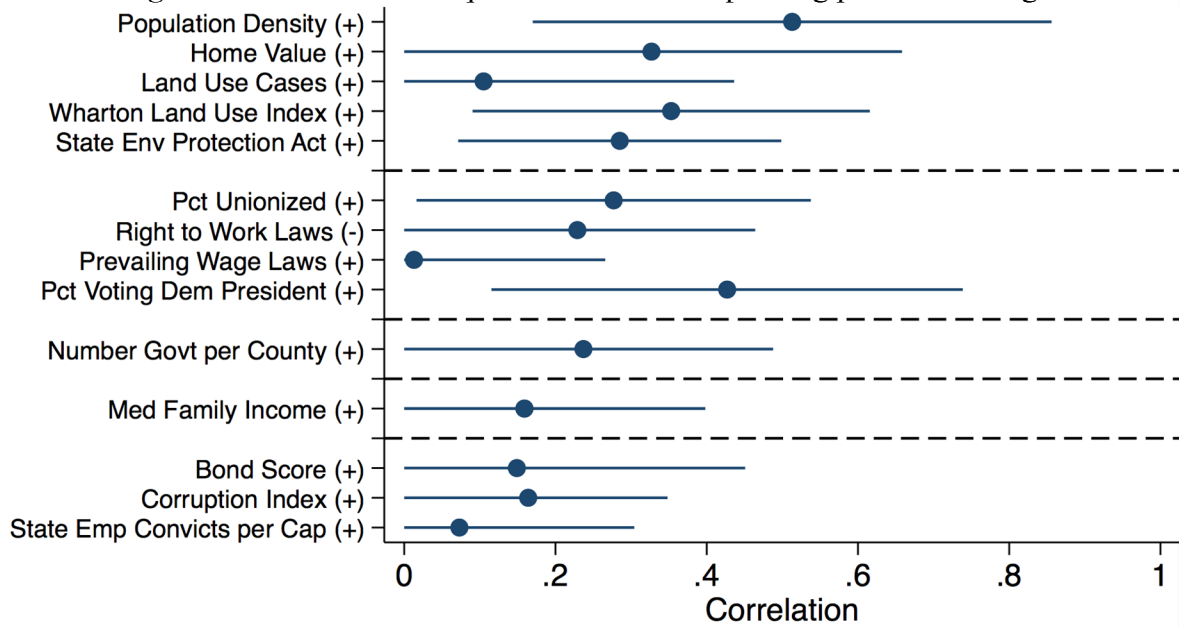


Figure 8. Share of Spending on Preliminary Engineering and Right of Way

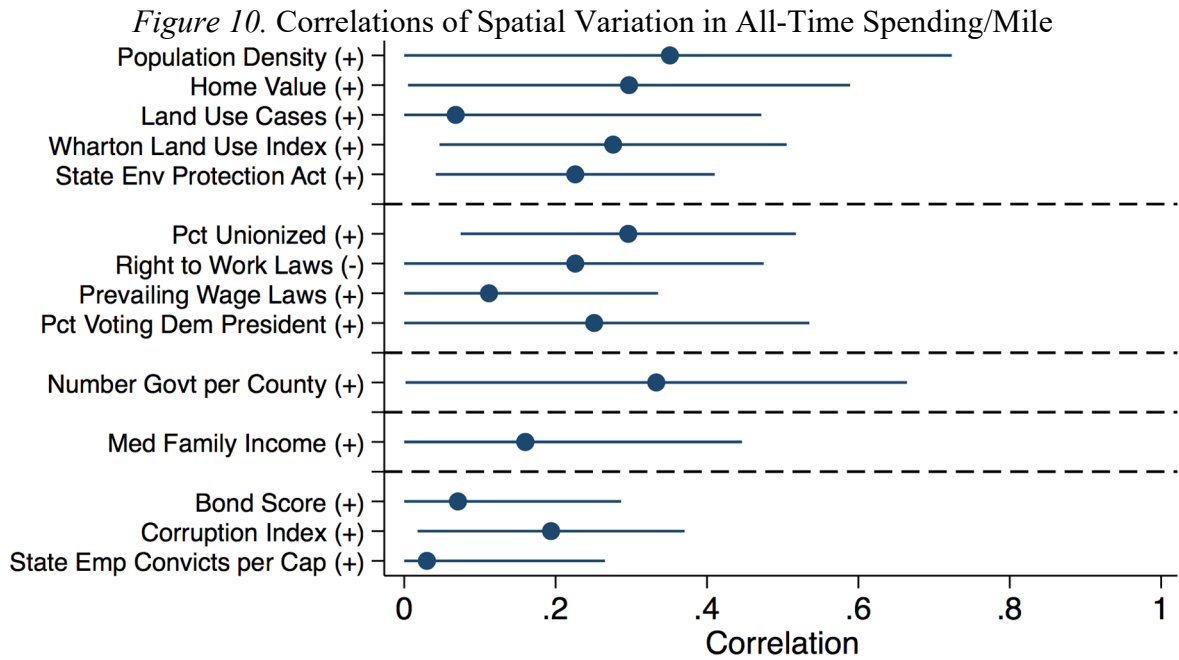


Notes: Total spending on PE/ROW as a percentage of combined total spending shown in black line at 17.7%.

Figure 9. Correlations of Spatial Variation in Spending per Mile Changes



Notes: This figure shows the correlation of various state-level characteristics with the difference in spending per mile after versus before 1970, weighted by miles built. Spending per mile measures are net of geographic covariates and are produced using the residuals from column (3) of Table 2. Each dot is the absolute value of the correlation, with the sign in parenthesis next to the variable name. Horizontal bars show the 95% confidence interval (truncated at zero for presentation). See column (4) in Appendix Table A3 for the corresponding estimates.



Notes: This figure shows the correlation of various state-level characteristics with all-time spending per mile, weighted by miles built. Spending per mile measures are net of geographic covariates and are produced using the residuals from column (3) of Table 2. Each dot is the absolute value of the correlation, with the sign in parenthesis next to the variable name. Horizontal bars show the 95% confidence interval (truncated at zero for presentation). See column (1) in Appendix Table A3 for the corresponding estimates.

Table 1. Summary Statistics of New Regression Covariates

	mean	sd	min	max
Millions of 2016 USD per Mile	11.59	13.88	0.05	865.79
Pop. Density (1k per Sq. Mi.)	0.50	0.64	0.00	8.01
Pop. Density * 1[Year > 1970]	0.17	0.45	0.00	5.35
Share Intersecting Wetlands, Rivers, & Other Waters	0.03	0.03	0.00	0.33
Slope (Degrees)	3.00	1.66	0.11	22.22
Structure Density	0.46	0.32	0.00	3.63
Segment Wiggleness	1.01	0.01	1.00	1.14
Years to Complete	1.71	1.60	0.00	17.81
Observations	269			

Notes: Years 1958-1993. Summary statistics are weighted by mileage.

Table 2. Effect of Geography and Time on Spending per Mile (Millions of 2016 USD)

	(1)	(2)	(3)	(4)
Yr='64-'70	0.44 (0.73)	0.13 (1.17)	1.32 (0.85)	1.03 (0.90)
Yr='71-'75	3.90** (1.08)	3.95** (1.61)	4.57*** (1.19)	4.66*** (1.43)
Yr='76-'81	7.71*** (1.66)	8.43*** (1.98)	7.84*** (1.55)	8.85*** (1.75)
Yr='82-'87	16.30*** (2.95)	15.98*** (3.19)	15.24*** (2.85)	15.94*** (3.18)
Yr='88-'93	26.03*** (7.67)	25.66*** (7.94)	22.14*** (7.63)	24.06*** (8.48)
Pop Density (1k per Sq. Mi.)			9.40*** (1.40)	6.68*** (2.44)
Share Intersecting Wetlands, Rivers, & Other Waters			19.38* (9.88)	-0.36 (34.10)
Slope (Degrees)			1.18*** (0.31)	0.62 (0.60)
State FE		X		X
Observations	269	269	269	269
R^2	0.141	0.363	0.351	0.406
Adjusted R^2	0.125	0.210	0.331	0.253

Notes: Mean of the outcome variable is 11.59. Standard errors clustered by state. Regressions are weighted by mileage. Excluded time period category is for 1958-1963. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

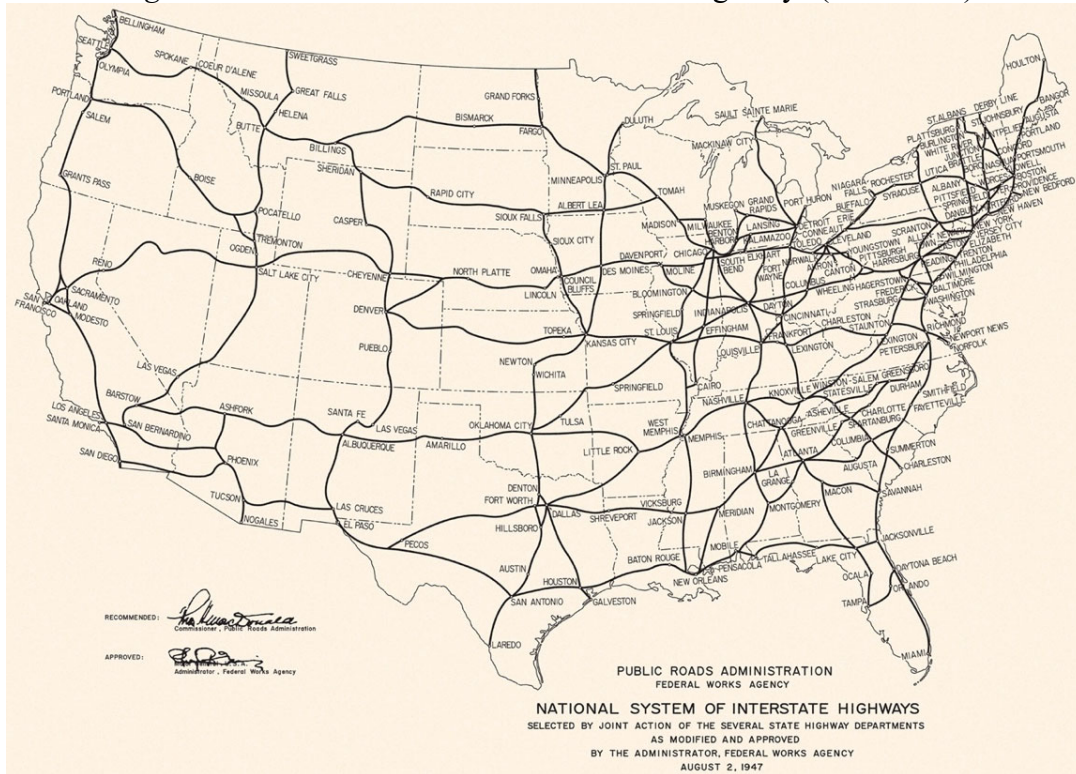
Table 3. Effect on Spending per Mile (Millions of 2016 USD)

	(1)	(2)	(3)	(4)	(5)	(6)
Yr='64-'70	1.03 (0.90)	1.04 (0.99)	0.76 (0.93)	2.43* (1.39)	2.01 (1.42)	0.36 (0.94)
Yr='71-'75	4.66*** (1.43)	5.01*** (1.48)	3.95** (1.55)	7.72*** (2.66)	6.98*** (2.43)	-0.26 (1.77)
Yr='76-'81	8.85*** (1.75)	8.24*** (1.62)	7.52*** (1.75)	12.21*** (3.15)	10.03*** (2.86)	3.53* (1.96)
Yr='82-'87	15.94*** (3.18)	13.12*** (3.20)	13.29*** (3.35)	18.63*** (3.87)	13.44*** (4.09)	9.90*** (3.40)
Yr='88-'93	24.06*** (8.48)	22.10*** (8.14)	19.88** (8.63)	28.87*** (10.24)	22.74** (10.01)	17.13* (8.53)
Pop Density (1k per Sq. Mi.)	6.68*** (2.44)	2.80 (2.32)	4.22 (2.86)	6.75*** (2.45)	1.16 (2.74)	2.81 (1.79)
Pop Density x 1[Year>1970]						8.92*** (3.19)
Share Intersecting Wetlands, Rivers, & Other Waters	-0.36 (34.10)	-11.22 (31.96)	-14.57 (35.95)	0.14 (30.96)	-22.29 (32.65)	10.86 (32.69)
Slope (Degrees)	0.62 (0.60)	1.10* (0.64)	-2.01 (1.55)	0.81 (0.54)	-1.23 (1.66)	0.99 (0.59)
Structure Density		17.53*** (4.96)			14.96*** (5.02)	
Segment Wiggleness			970.60* (581.22)		894.83 (604.50)	
Years to Complete				-1.11 (0.84)	-0.97 (0.70)	
Med Family Income (10K USD)						
Med Family Income x 1[Year>1970]						
State FE	X	X	X	X	X	X
Observations	269	269	269	269	269	269
R ²	0.406	0.435	0.450	0.411	0.476	0.437
Adjusted R ²	0.253	0.286	0.305	0.256	0.332	0.288

Notes: Mean of the outcome variable is 11.59. Standard errors clustered by state. Regressions are weighted by mileage. Excluded time period category is for 1958-1963. * p<0.10, ** p<0.05, *** p<0.01

Appendix Figures and Tables

Figure A1. Planned Routes of the Interstate Highways (circa 1947)



Source: Federal Highway Administration (2017c)

Figure A2. Timing of Interstate Opening
Figure A2i. Interstates Opening 1950-1959

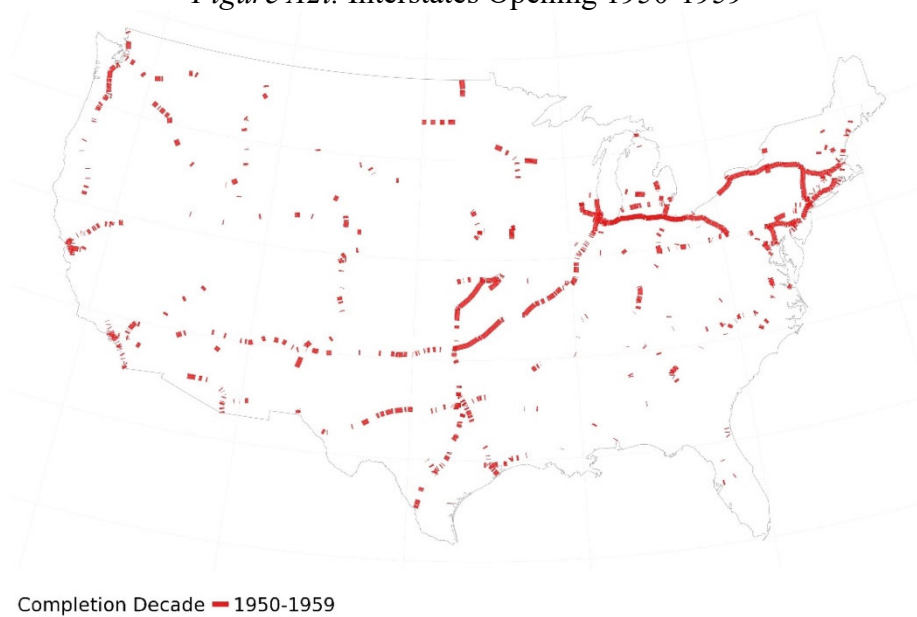


Figure A2ii. Interstates Opening 1960-1969

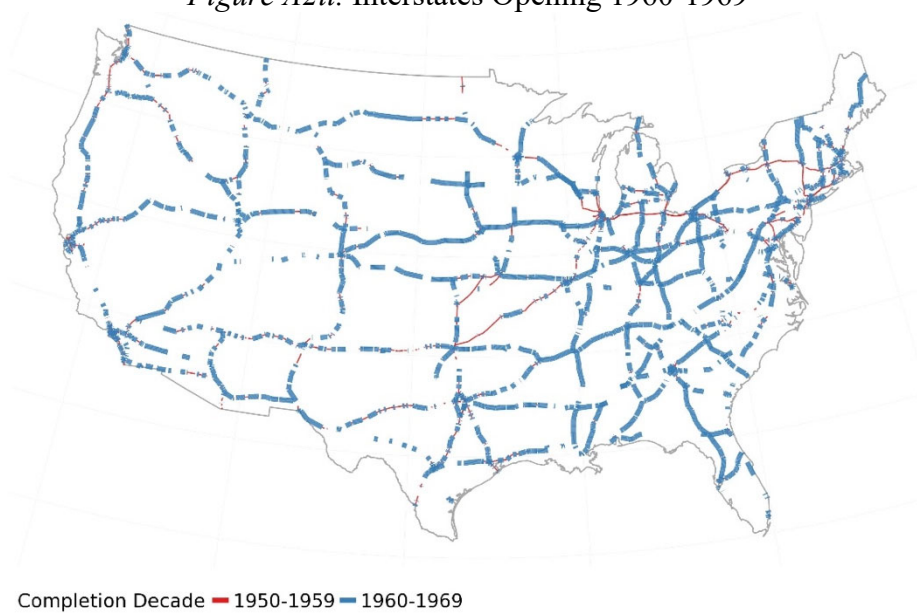


Figure A2iii. Interstates Opening 1970-1979

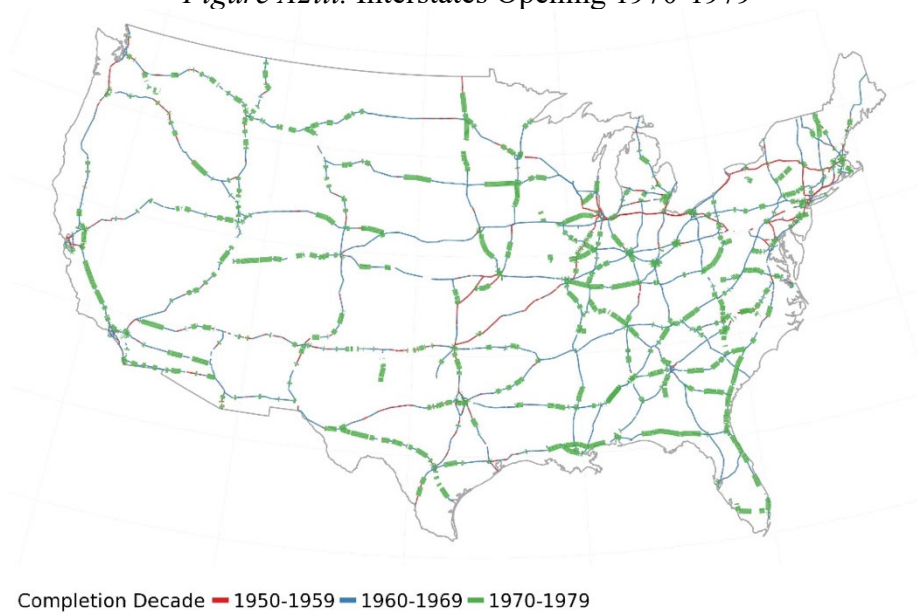


Figure A2iv. Interstates Opening 1980-1989

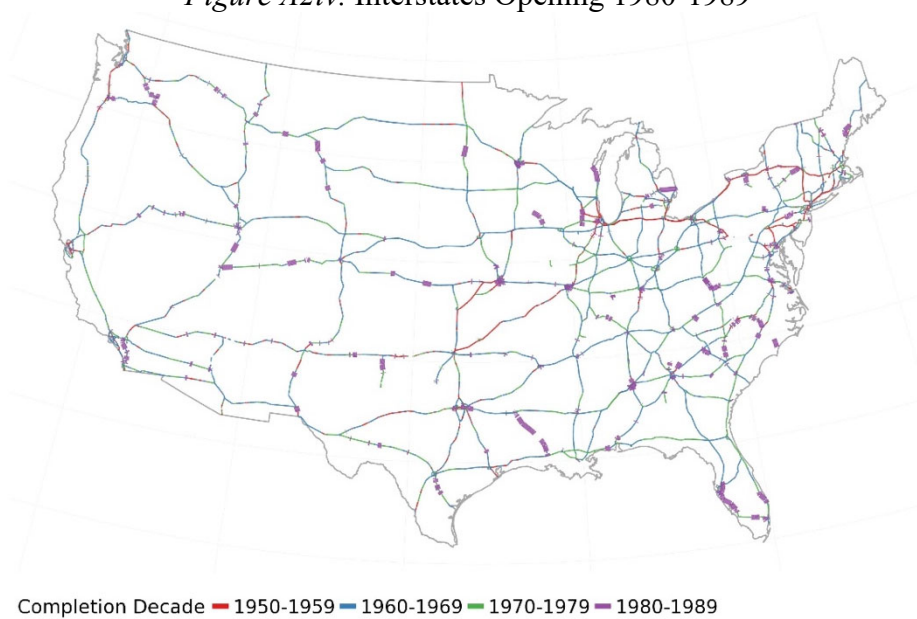


Figure A2v. Interstates Opening 1990-1993

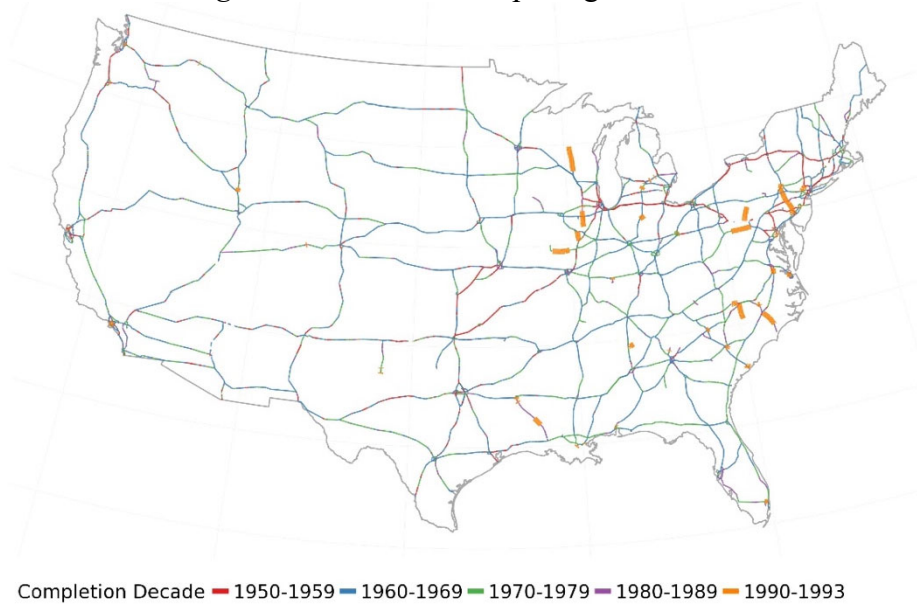


Figure A2vi. Full Interstate System

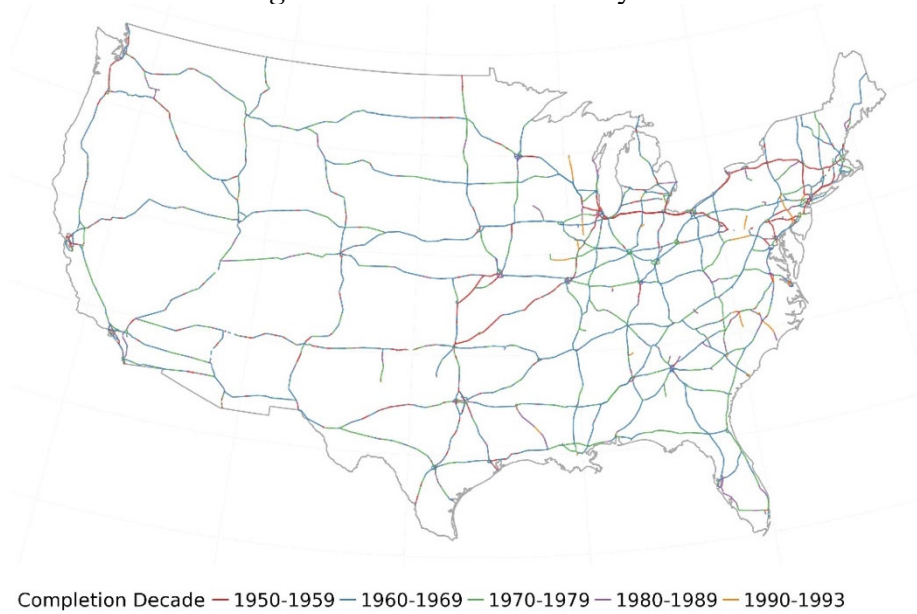


Figure A3. Interstate Spending per Mile by State (Not Controlling for Geography)

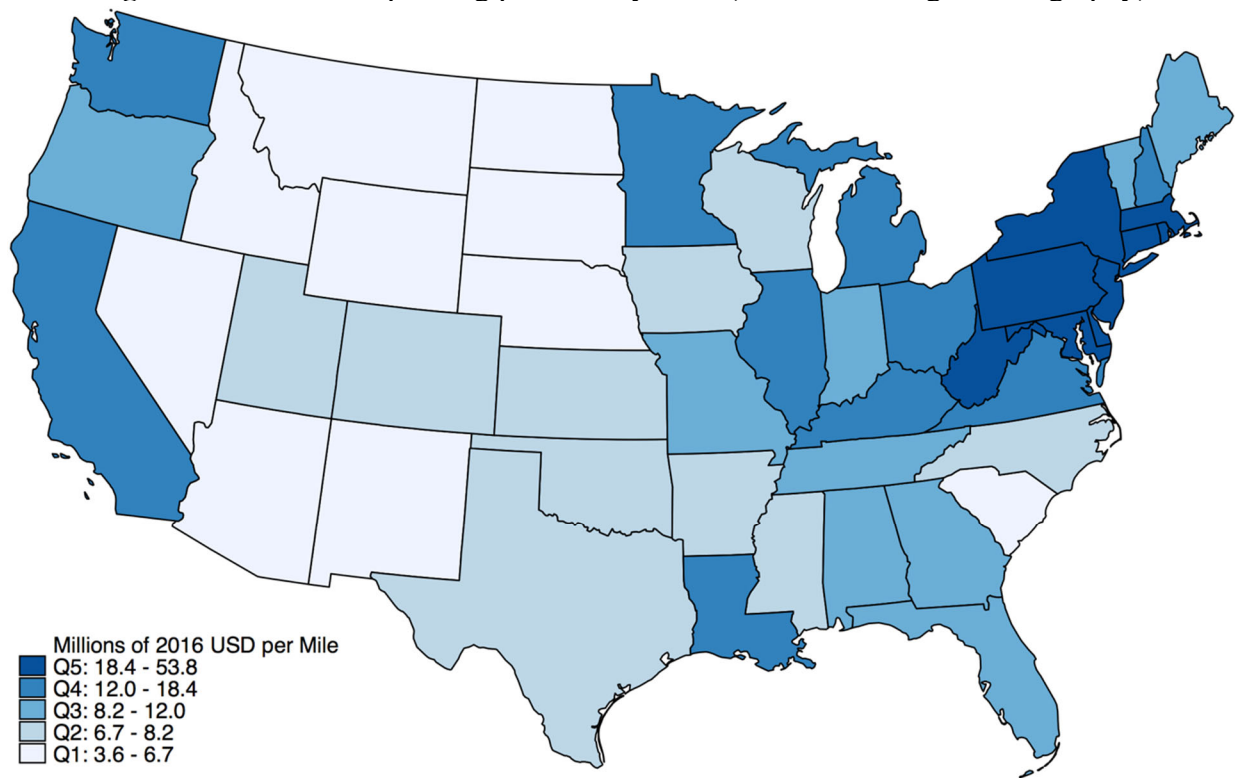


Figure A4. Spending per Mile: Pre-1970 vs. Post-1970 (Not Controlling for Geography)

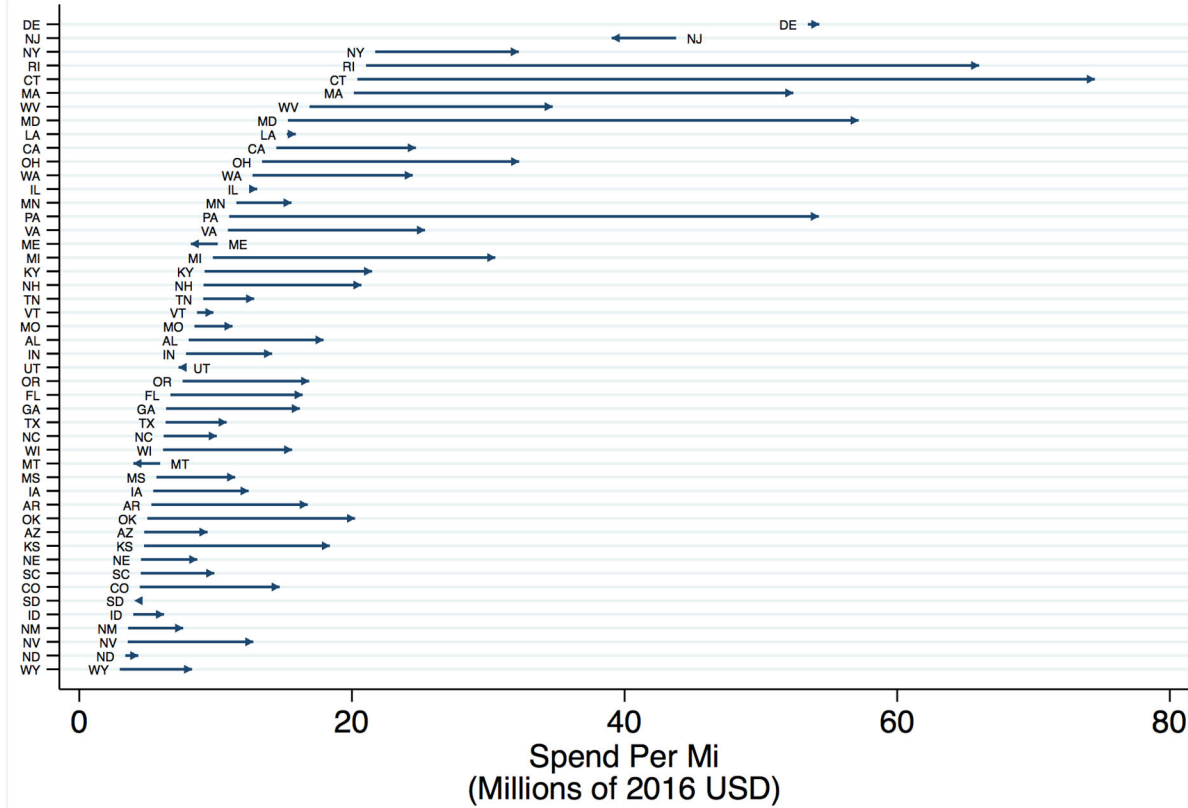
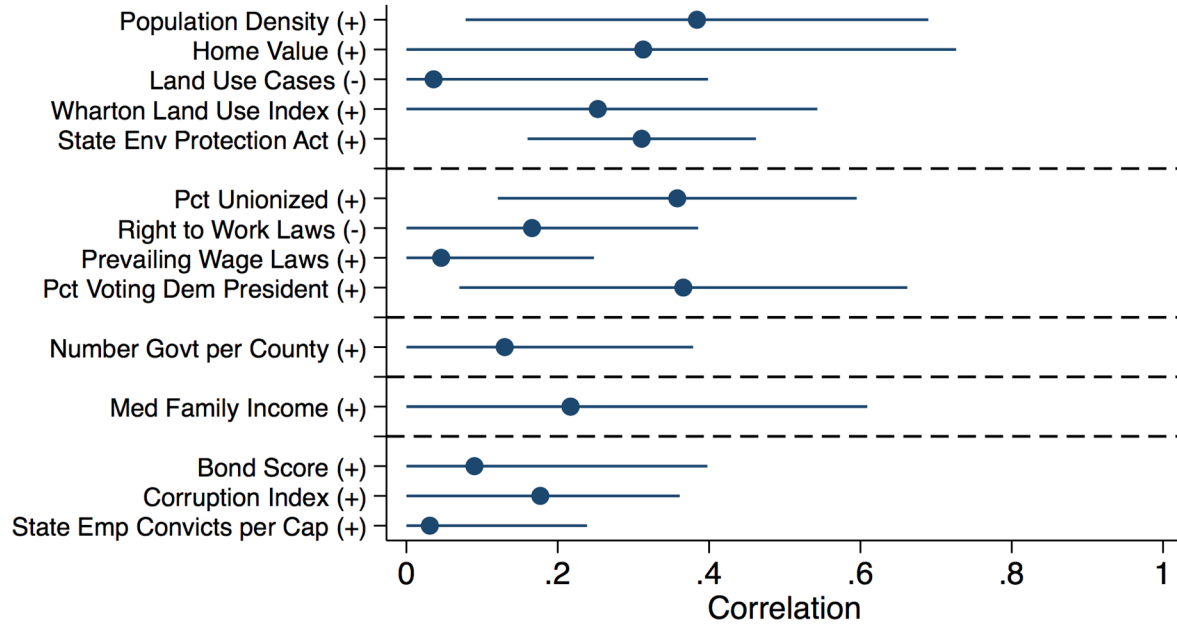


Figure A5. Correlations of Spatial Variation in Spending per Mile Changes; With Region Fixed Effects



Notes: This figure shows, conditional on census region, the correlation of various state-level characteristics with the difference in spending per mile after versus before 1970, weighted by miles built. Spending per mile measures are net of geographic covariates and are produced using the residuals from column (3) of Table 2. Each dot is the absolute value of the correlation, with the sign in parenthesis next to the variable name. Horizontal bars show the 95% confidence interval (truncated at zero for presentation). See column (4) in Appendix Table A4 for the corresponding estimates.

Figure A6. Pedestrian Plazas Across I-696 in Oak Park



Notes: One of the pedestrian plazas is outlined.
Source: Michigan Department of Transportation (2003).

Table A1. Mileage Openings Regressed on Leads and Lags of Expenditures

	(1)
Year X Expenditure	41.096*** (15.242)
Year X-1 Expenditure	33.474*** (10.981)
Year X-2 Expenditure	14.877** (5.802)
Year X-3 Expenditure	3.201 (9.450)
Year X-4 Expenditure	5.282 (9.355)
Year X-5 Expenditure	-8.180 (6.290)
Year X-6 Expenditure	18.128 (10.809)
Year X-7 Expenditure	-15.246 (10.948)
Year X-8 Expenditure	-8.848 (11.143)
Year X-9 Expenditure	7.300 (5.230)
Year X-10 Expenditure	-9.328 (6.812)
Year X+1 Expenditure	-6.694 (13.358)
Year X+2 Expenditure	-11.992 (12.201)
Year X+3 Expenditure	8.936 (13.148)
Year X+4 Expenditure	0.392 (12.147)
Year X+5 Expenditure	18.988 (11.826)
Constant	-2.659 (3.911)
Observations	1100
R^2	0.580
Adjusted R^2	0.555

Note: Robust standard errors clustered at the state level. Regression includes state FE. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Table A2. Effect of Geography on Spending per Mile: Robustness

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Yr='64-'70	1.03 (0.90)	-1.50 (3.01)	0.12 (1.20)	1.00 (0.87)	1.68 (1.15)	0.96 (0.92)	1.03 (0.91)	1.00 (0.92)	1.71 (1.14)
Yr='71-'75	4.66*** (1.43)	7.33* (3.81)	3.96** (1.60)	4.63*** (1.44)	4.61*** (1.69)	4.70*** (1.42)	4.46*** (1.40)	4.77*** (1.43)	4.34** (1.62)
Yr='76-'81	8.85*** (1.75)	21.47** (8.38)	8.39*** (2.08)	8.81*** (1.62)	9.48*** (1.90)	9.15*** (1.85)	9.00*** (1.84)	8.77*** (1.78)	9.53*** (1.90)
Yr='82-'87	15.94*** (3.18)	44.10* (22.55)	15.92*** (3.25)	16.06*** (3.15)	15.14*** (3.29)	15.60*** (3.18)	15.63*** (3.21)	16.08*** (3.31)	15.14*** (3.28)
Yr='88-'93	24.06*** (8.48)	60.02*** (20.91)	25.25*** (8.74)	24.01*** (8.16)	23.75*** (8.20)	23.60*** (8.50)	23.44*** (8.50)	24.61*** (8.67)	23.24*** (8.27)
Pop Density (1K per Sq. Mi.)	6.68*** (2.44)	9.72 (7.47)		7.01*** (2.17)	6.82*** (1.99)	12.95** (5.03)	1.44 (13.52)	6.63** (2.47)	-1.37 (13.42)
Pop Density (2 nd order)						-2.31 (2.46)	14.61 (20.90)		15.27 (20.42)
Pop Density (3 rd order)						0.17 (0.24)	-8.34 (11.17)		-7.60 (10.79)
Pop Density (4 th order)							1.62 (2.22)		1.36 (2.13)
Pop Density (5 th order)							-0.10 (0.14)		-0.08 (0.13)
Static Pop Density			0.01 (0.02)						
Share Intersecting Wetlands, Rivers, & Other Waters	-0.36 (34.10)	-125.62 (155.64)	-4.39 (36.83)		-18.40 (34.98)	0.83 (32.91)	2.12 (33.22)	-101.42 (272.33)	-59.66 (143.53)
Share Wetlands (2 nd order)								1658.73 (3709.11)	-39.66 (1326.89)
Share Wetlands (3 rd order)								-11320.77 (17915.97)	971.06 (3048.33)
Share Wetlands (4 th order)								24060.72 (27801.95)	
Slope (Degrees)	0.62 (0.60)	-2.72 (2.18)	0.23 (0.73)	0.56 (0.61)	0.30 (0.67)	0.57 (0.62)	0.46 (0.64)	0.66 (0.70)	0.07 (0.78)
County Wetland Density				-5.51 (6.55)					
Max Summer Temp (deg F)					1.55** (0.62)				1.56** (0.60)
Min Winter Temp (deg F)					0.06 (0.51)				0.20 (0.54)
Annual Rainfall (Inches)					0.31 (0.34)				0.18 (0.32)
State FE	X	X	X	X	X	X	X	X	X
Eco-Region Indicators					X				X
Unweighted		X							
Observations	269	269	269	269	269	269	269	269	269
R ²	0.406	0.316	0.363	0.408	0.442	0.411	0.413	0.409	0.450
Adjusted R ²	0.253	0.139	0.199	0.255	0.256	0.252	0.248	0.246	0.244

Notes: Mean of the outcome variable is 11.59. Standard errors clustered by state. Regressions are weighted by mileage. Excluded time period category is for 1958-1963. * p<0.10, ** p<0.05, *** p<0.01

Table A3. Correlates of Millions of 2016 USD Construction Expenditures per Mile (from residuals given by a miles-weighted regression of Spend/Mi on select covariates) across States; No Region Fixed Effects

		(1)		(2)		(3)		(4)	
		All Time	(se)	Pre-1970	(se)	Post-1970	(se)	Change over 1970	(se)
Citizen Voice	Population Density	0.351	(0.19)	-0.066	(0.294)	0.555	(0.129)	0.513	(0.175)
	Home Value	0.297	(0.149)	0.038	(0.226)	0.393	(0.141)	0.327	(0.169)
	Land Use Cases	0.068	(0.206)	0.057	(0.163)	0.149	(0.185)	0.105	(0.169)
	Wharton Land Use Index	0.276	(0.117)	0.027	(0.198)	0.418	(0.103)	0.353	(0.134)
	State Environmental Protection Act	0.226	(0.094)	-0.095	(0.113)	0.280	(0.090)	0.285	(0.109)
Labor	Pct. Unionized	0.296	(0.113)	0.058	(0.127)	0.346	(0.125)	0.277	(0.133)
	Right to Work Laws	-0.226	(0.127)	-0.047	(0.105)	-0.286	(0.123)	-0.229	(0.12)
	Prevailing Wage Laws	0.112	(0.114)	0.116	(0.117)	0.073	(0.116)	0.013	(0.129)
	Pct. Voting Dem. President	0.251	(0.145)	-0.124	(0.098)	0.427	(0.167)	0.427	(0.159)
Fragmentation	Number Govt per County	0.333	(0.169)	0.138	(0.208)	0.340	(0.144)	0.237	(0.128)
Income	Median Family Income	0.160	(0.146)	0.051	(0.163)	0.208	(0.114)	0.159	(0.122)
Government Quality	Bond Score	0.071	(0.110)	-0.022	(0.137)	0.160	(0.133)	0.149	(0.154)
	Corruption Index	0.194	(0.090)	0.037	(0.082)	0.207	(0.098)	0.164	(0.094)
	State Employee Convictions per Capita	0.030	(0.120)	-0.028	(0.106)	0.070	(0.116)	0.073	(0.118)
Other	Structure Density	0.294	(0.147)	-0.037	(0.161)	0.393	(0.161)	0.359	(0.173)
	Segment Wiggleness	0.202	(0.146)	0.006	(0.114)	0.220	(0.093)	0.189	(0.082)
	Years to Complete	-0.080	(0.155)	0.161	(0.124)	-0.088	(0.141)	-0.146	(0.128)
	Number of Lanes	0.154	(0.101)	-0.072	(0.075)	0.222	(0.111)	0.224	(0.098)
	Share Intersecting Wetlands, Rivers, & Other Waters	0.059	(0.118)	0.188	(0.203)	0.022	(0.106)	-0.062	(0.142)
	Slope	0.032	(0.158)	-0.133	(0.114)	0.223	(0.140)	0.252	(0.128)
	Pct. Black	0.069	(0.118)	0.037	(0.086)	0.029	(0.102)	0.009	(0.101)

Notes: Each coefficient is from a 48-observation state-level bivariate regression of spending per mile (millions of 2016 USD) on the covariate named on left. Regressions are weighted by mileage. The first column uses residuals averaged (with miles weighting) across all years from a state-year level miles-weighted regression of spending per mile on geographic covariates as the LHS variable. The third and fifth use, respectively, averaged (with miles weighting) residuals pre-1970, post-1970, and for the change after 1970 from this same regression for the LHS variable. Standard errors are clustered by state and both LHS and RHS variables are standardized and mean-centered.

Table A4. Correlates of Spending per Mile across States; with Region Fixed Effects

		(1)		(2)		(3)		(4)	
		All-Time	(se)	Pre-1970	(se)	Post-1970	(se)	Change after 1970	(se)
Citizen Voice	Population Density	0.245	(0.185)	-0.125	(0.233)	0.378	(0.145)	0.384	(0.156)
	Home Value	0.445	(0.161)	0.120	(0.238)	0.418	(0.166)	0.313	(0.211)
	Land Use Cases	0.076	(0.202)	0.125	(0.157)	0.020	(0.187)	-0.036	(0.185)
	Wharton Land Use Index	0.408	(0.149)	0.136	(0.227)	0.358	(0.104)	0.253	(0.148)
	State Environmental Protection Act	0.338	(0.107)	-0.057	(0.128)	0.328	(0.068)	0.311	(0.077)
Labor	Pct. Unionized	0.440	(0.164)	0.074	(0.108)	0.446	(0.132)	0.358	(0.121)
	Right to Work Laws	-0.273	(0.150)	-0.081	(0.081)	-0.230	(0.123)	-0.166	(0.112)
	Prevailing Wage Laws	0.171	(0.129)	0.143	(0.127)	0.123	(0.105)	0.046	(0.103)
	Pct. Voting Dem. President	0.162	(0.149)	-0.217	(0.148)	0.312	(0.137)	0.366	(0.151)
Fragmentation	Number Govt per County	0.380	(0.112)	0.203	(0.192)	0.249	(0.072)	0.130	(0.127)
Income	Median Family Income	0.386	(0.176)	0.164	(0.234)	0.330	(0.162)	0.217	(0.200)
Government Quality	Bond Score	0.047	(0.147)	-0.010	(0.156)	0.098	(0.140)	0.090	(0.157)
	Corruption Index	0.205	(0.077)	0.042	(0.070)	0.224	(0.096)	0.177	(0.094)
	State Employee Convictions per Capita	-0.048	(0.139)	-0.061	(0.111)	0.005	(0.115)	0.031	(0.106)
Other	Structure Density	0.201	(0.173)	-0.074	(0.113)	0.259	(0.161)	0.258	(0.151)
	Segment Wiggleness	0.170	(0.152)	-0.009	(0.122)	0.190	(0.078)	0.170	(0.061)
	Years to Complete	-0.122	(0.150)	0.200	(0.127)	-0.184	(0.124)	-0.247	(0.119)
	Number of Lanes	0.192	(0.102)	-0.053	(0.084)	0.245	(0.084)	0.237	(0.081)
	Share Intersecting Wetlands, Rivers, & Other Waters	-0.034	(0.111)	0.186	(0.182)	-0.119	(0.085)	-0.184	(0.124)
	Slope	0.026	(0.183)	-0.107	(0.157)	0.099	(0.113)	0.133	(0.102)
	Pct. Black	0.008	(0.157)	-0.007	(0.153)	0.066	(0.131)	0.061	(0.133)

Notes: Each coefficient is from a 48-observation state-level bivariate regression of spending per mile (millions of 2016 USD) on the covariate named on left. Regressions are weighted by mileage and additionally add fixed effects for Census Regions. The first column uses residuals averaged (with miles weighting) across all years from a state-year level miles-weighted regression of spending per mile on geographic covariates as the LHS variable. The third and fifth use, respectively, averaged (with miles weighting) residuals pre-1970, post-1970, and for the change after 1970 from this same regression for the LHS variable. Standard errors are clustered by state and both LHS and RHS variables are standardized and mean-centered.

Appendix Table A5. Effect of Policy Variables on Change in Millions of 2016 Dollars per Mile

	(1) Change after 1970	(2) Change after 1970	(3) Change after 1970	(4) Change after 1970	(5) Change after 1970	(6) Change after 1970
Pct Unionized	0.18 (0.14)	0.32*** (0.12)	0.26* (0.13)			
Pct Voting Dem President				0.26 (0.17)	0.32* (0.17)	0.29** (0.14)
Population Density	0.31* (0.18)			0.30 (0.18)		
Wharton Land Use Index		0.21 (0.15)			0.14 (0.16)	
State Environmental Protection Act			0.25*** (0.09)			0.23*** (0.08)
Region FE	X	X	X	X	X	X
Observations	48	48	48	48	48	48
R^2	0.358	0.328	0.346	0.390	0.342	0.372
Adjusted R^2	0.282	0.248	0.268	0.317	0.264	0.298

Notes: Mean of the outcome variable is 0. Standard errors clustered by state and the RHS and LHS variables are standardized. The LHS variable uses residuals from column 3 of Table 2. Each variable represents a miles-weighted average across years. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

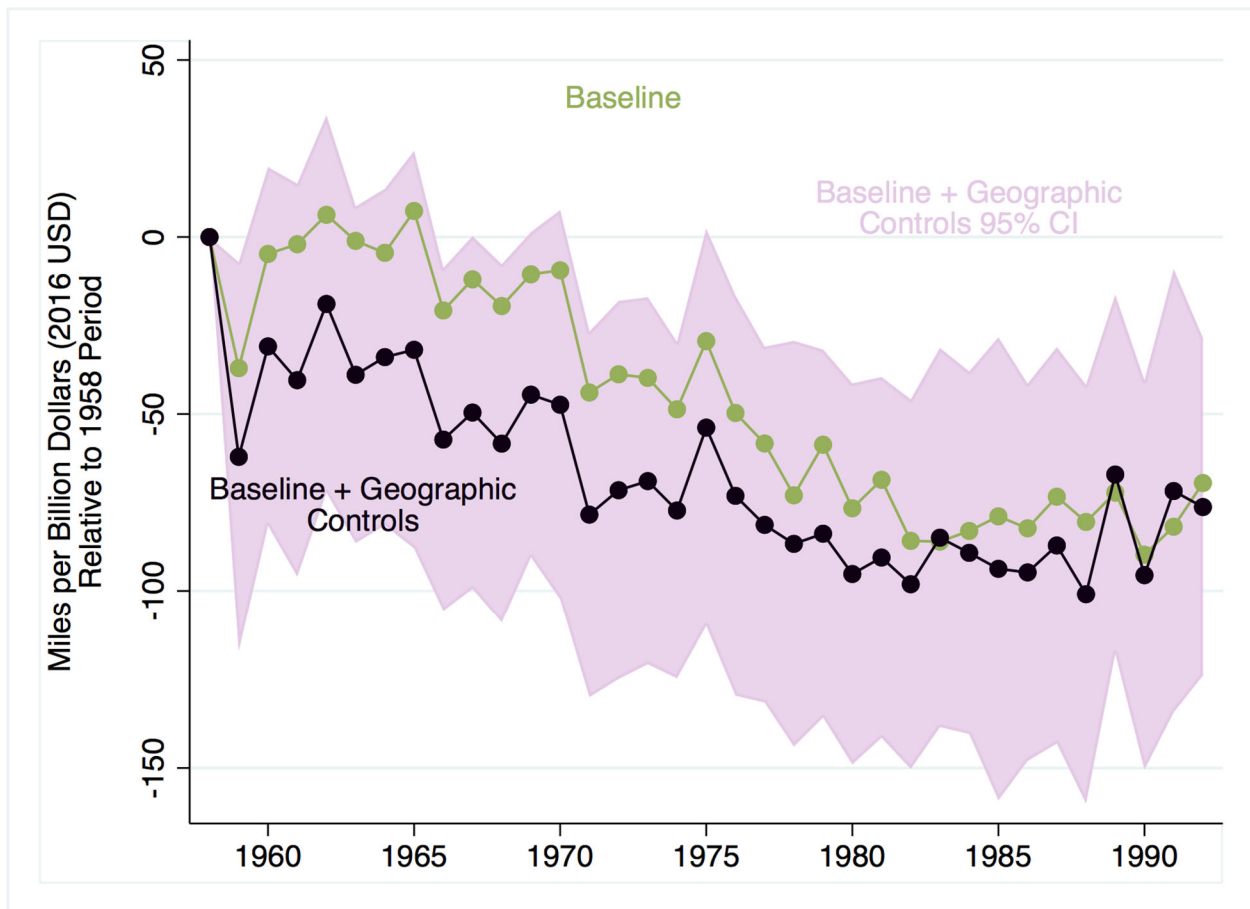
Appendix Table A6. Correlation of Covariates Pre-1970, Post-1970, and Change from Pre-1970

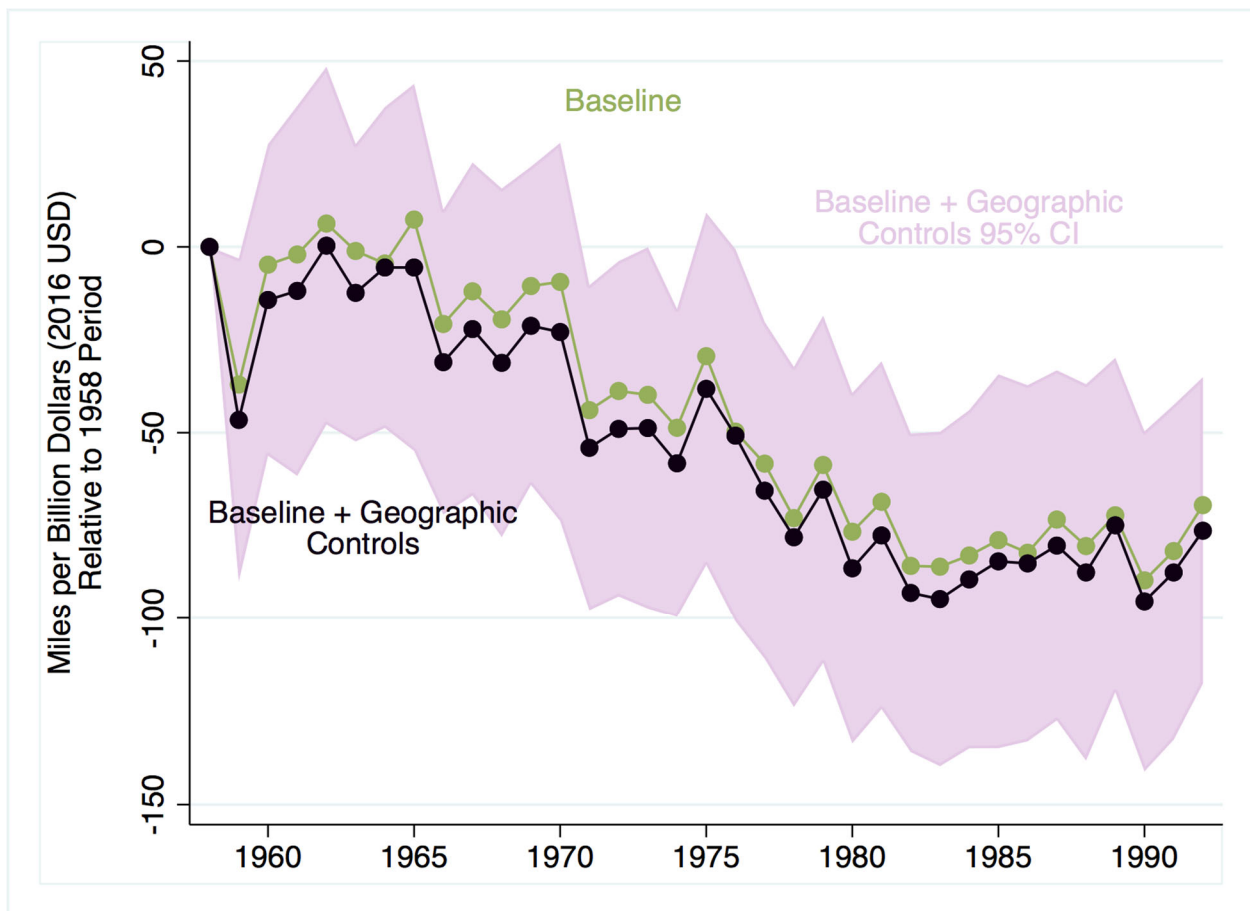
	Pre-1970	(se)	Change	(se)	R ²
Population Density	0.618	(0.157)	0.11	(0.246)	0.336
Home Value	0.235	(0.197)	0.276	(0.185)	0.165
Land Use Cases	0.015	(0.206)	0.182	(0.177)	0.035
Wharton Land Use Index	0.351	(0.125)	0.004	(0.092)	0.124
State Environmental Protection Act	-0.166	(0.159)	0.449	(0.222)	0.13
Pct. Unionized	0.564	(0.238)	0.386	(0.221)	0.138
Right to Work Laws	-0.243	(0.129)	-0.233	(0.081)	0.1
Prevailing Wage Laws	0.02	(0.164)	0.074	(0.128)	0.005
Pct. Voting Dem President	0.652	(0.207)	0.441	(0.166)	0.164
Median Family Income	0.27	(0.144)	0.17	(0.175)	0.056
Number Govt per County	-0.037	(0.157)	0.458	(0.202)	0.191
Bond Score	0.116	(0.126)	0.393	(0.218)	0.143
Corruption Index	0.137	(0.094)	0	(0)	0.019
State Employee Convictions per Capita	0.072	(0.135)	0.113	(0.096)	0.021
Share Intersecting Wetlands, Rivers, & Other Waters	-0.027	(0.188)	-0.023	(0.15)	0.002
Pct. Black	0.206	(0.138)	0.458	(0.182)	0.159
Structure Density	0.354	(0.184)	0.162	(0.174)	0.13
Segment Wiggleness	0.145	(0.087)	0.207	(0.123)	0.053
Years to Complete	-0.057	(0.184)	0.02	(0.207)	0.005

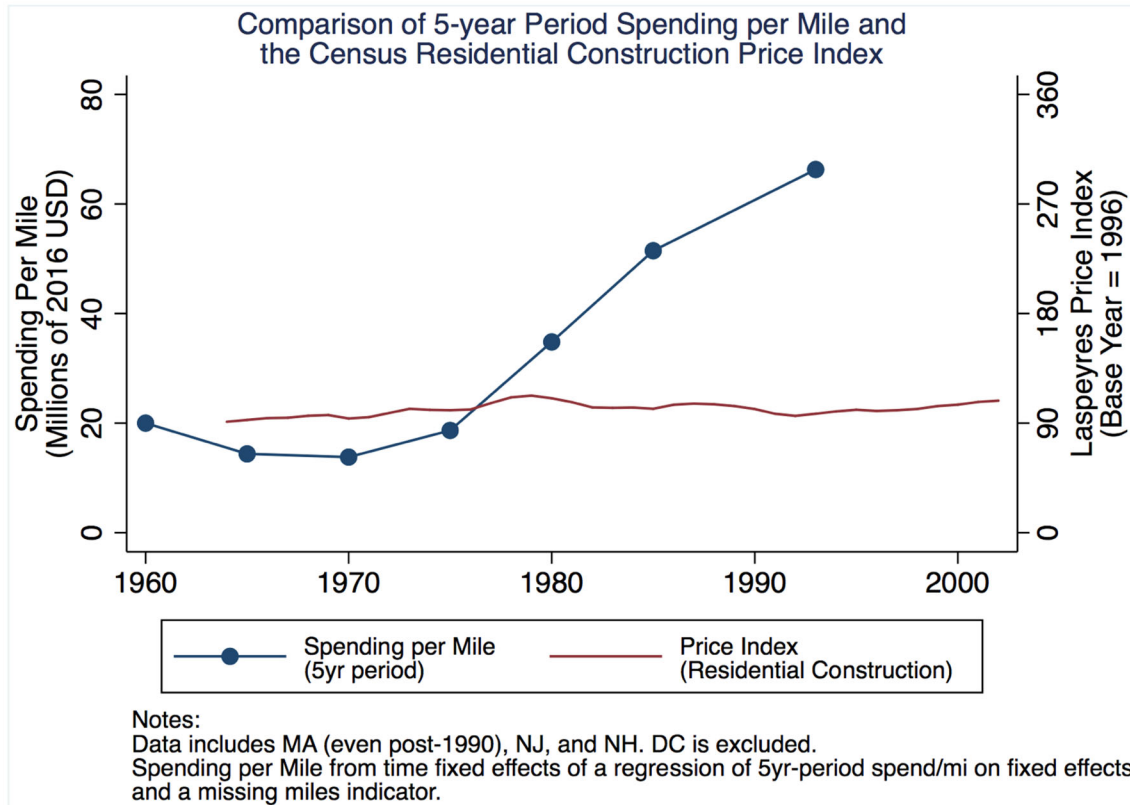
Notes: Columns 1 and 3 give estimates from individual regressions of state-averaged residuals (from a state-year level regression of spending per mile on geographic controls, period FE, and stateFE) on the (state-averaged) covariate at left pre-1970 and across 1970 (i.e., the post-1970 average less the pre). Columns 2 and 4 give the respective standard errors, and column 5 gives the regression's R squared value. Both the LHS and RHS variables are standardized. RI is excluded from the regressions because they are miles-weighted and miles is 0 from 1976 on in RI.

Jacob: additional Appendix figures

- Alternative spec R-squared plot
- Jacob appendix Tables: Leah's cut-off point regression
- Alternative over-time specification







cut: move to appendix?

Because of measurement issues, we prefer to use a (less intuitive) measure of miles per dollar. We observe the exact year in which spending takes place, and the spending time series is quite smooth. Ideally, we would observe an annual measure of construction output. Instead, we observe the year in which each highway segment opens. This makes our measure of miles completed quite lumpy relative to the spending data. Characterizing the lumpiness of miles completed as measurement error, it is better to locate that measurement error in the numerator rather than the denominator to yield unbiased estimates.⁵⁶

⁵⁶ When x appears in the numerator, as in the function x , it is a linear operator, and mean-zero measurement error averages out. In contrast, when x appears in the denominator, as in the function $\frac{1}{x}$, the function is no longer a linear operator; measurement error in x , which is in the denominator, yields biased estimates. To see this, suppose that we have two observations of x , which has a true value of 2 but is mismeasured as having values 1 and 3. The function x will have the correct average of 2. But the function $\frac{1}{x}$ has the incorrect average of $\frac{2}{3}$ instead of the correct average of $\frac{1}{2}$.

Using this preferred measure of miles per billion dollars, Figure 2 again shows annual national data with a light line and a three-year moving average with the darker line. We see that in the 1960s, the US produced over 100 miles of Interstate per billion dollars (2016 USD) of spending. By the early 1990s, this figure fell by more than 80 percent to roughly 20 miles of Interstate per billion 2016 dollars.