Infrastructure Costs

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There is widespread consensus that US infrastructure investment—and infrastructure quality—has been on the decline. In response, politicians across the ideological spectrum have called for increased infrastructure spending. How much infrastructure we would get depends on how much output is produced per dollar of spending. Yet we know surprisingly little about infrastructure 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 per mile over the history of its construction.

We make two 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 changes in observed geography over time do not explain these changes. Second, we provide suggestive evidence of the determinants of the increase in spending per mile. In particular, the increased spending per mile coincides with the rise of "citizen voice" in government decision-making in the early 1970s. And rising incomes and housing prices nearly completely statistically explain the increase in costs. We also largely rule out several common explanations for rising costs, such as increases in per-unit labor or materials prices.

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1. Introduction

Although the United States spends over $400 billion per year on infrastructure, there is a consensus that infrastructure investment has been on the decline and with it the quality of US

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infrastructure.[1] Politicians across the ideological spectrum have responded with calls for increased spending on infrastructure to repair this infrastructure deficit.

Of course, the amount of infrastructure we get from this spending depends on how much output each dollar of spending yields. Unfortunately, there is a widespread belief that the US now gets less per dollar of infrastructure spending—both less than it used to, and less relative to other countries.[2] For example, Gordon and Schleicher (2015) argue that recent transit projects are more expensive in the US than in the rest of the world (see also Rosenthal (2017) and Levy (2013)). Apart from these sources, there is very little credible evidence on whether US infrastructure spending per unit has gone up over time. Much of the cutting edge in this area consists of *New York Times* exposés[3] and blog posts.[4] The issue of infrastructure costs is particularly important as calls for increased infrastructure spending are sometimes coupled 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 a bedeviling challenge of the diversity of infrastructure. 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.[5]

We aim to help fill this evidentiary gap by documenting and analyzing spending on new construction of the US Interstate System over the course of the second half of the twentieth

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[1] Shirley, Chad, "Spending on Infrastructure and Investment.," Congressional Budget Office (Mar. 1, 2017), https://www.cbo.gov/publication/52463, and 2017 Infrastructure Report Card, https://www.infrastructurereportcard.org/.

[2] 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/.

[3] 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.

[4] See https://pedestrianobservations.com/construction-costs/.

[5] 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. Swei (2018) uses macro data on infrastructure broadly defined and argues that a Baumol-type cost disease is increasing costs from the interwar period to the present.

century. Interstate highway construction is of particular interest because it is one of the largest infrastructure projects in American history.[6] Like many other forms of infrastructure, it was built with significant federal funding and was subject to a large set of environmental and labor regulations. Because the total number of Interstate miles is fixed, state decision-making is largely limited to highway design (within the federal standards) and construction implementation. In addition, and usefully for our analysis, Interstate highways are a relatively uniform product across space and time, particularly in comparison with other big-ticket items such as mass transit or airports. This relative uniformity makes for easier comparisons across time and space. At the same time, because states were responsible for construction, there is rich potential for geographic variation (as in Chetty et al. 2014).

To analyze Interstate construction spending, 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 data[7] and to combine these data with the number of Interstate miles completed in each year (Baum-Snow 2007). We combine these spending per mile ("costs") data with numerous other sources to measure the geographic, political, and legal determinants of costs. 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.

We make two main contributions. First, we document Interstate costs over time and reveal a dramatic increase in spending per mile of constructed Interstate.[8] In real terms, states spent approximately three times as much to construct a highway mile in the 1980s as they did in the early 1960s. This substantial increase persists even controlling for the pre-existing geography of Interstate construction. In other words, the bulk of the increase is not due to highway planners leaving the "hardest" sections until last in ways captured by observable differences in geography.

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[6] Erickson, Jennifer. 2012. "Top 10 U.S. Government Investments in 20th Century American Competitiveness." Center for American Progress. https://www.americanprogress.org/issues/economy/reports/2012/01/06/10930/top-10-u-s-government-investments-in-20th-century-american-competitiveness/; Davis, Jeff. 2016. "The 70-Year Trend in Federal Infrastructure Spending." *Eno Transportation Weekly.* Eno Transportation Center. https://www.enotrans.org/article/70-year-trend-federal-infrastructure-spending/.

[7] Smith, Haefen, and Zhu (1999) use the data from 1990-1994.

[8] Historically the Department of Transportation produced a Bid Price Index, but it was canceled out of reliability concerns. It was designed to measure 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 National Highway Construction Cost Index (NHCCI) starting in 2003, which again was rehauled out of reliability concerns and again was designed to measure input prices. FHWA, National Highway Construction Cost Index (NHCCI) 2.0 (2017), https://www.fhwa.dot.gov/policy/otps/nhcci/desc.cfm.

Our second contribution is to shed light on which hypotheses about increases in costs explain the temporal increase. To do so, we take advantage of the large dispersion in construction costs across states, even considering differing geography, that emerges in the later years of highway construction. Multiple plausible prominent hypotheses are likely *not* important. First, increases in real per unit input prices are an obvious potential cause of increased expenditure. However, we find that input prices for labor and materials move very little over the period and therefore cannot drive much of the increase in costs over time. Analogizing to an important question in the healthcare literature (Anderson et al. 2003, Skinner and Fisher 2010; Cooper et al. 2019), this result suggests that increases in quantities, rather than increases in prices, drove the increase in costs. Second, anything constant across time cannot alone explain the increase, and the temporal increase in costs is roughly invariant to the inclusion of state fixed effects. Thus, anything constant over time but varying at the state level—for example, legal system or geographic location—or national level is insufficient to explain the increase. 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. Finally, we have uncovered no evidence on changes in construction standards mandated by federal Interstate planners of a magnitude sufficient to appreciably impact costs.

We do find empirical evidence consistent with two hypotheses. The first is that the demand for more expensive Interstate highways increases with income, as either richer people are willing to pay for more expensive highways or in any case they can have their interests heard in the political process. The doubling in real median per capita income over the period accounts for roughly half of the increase in expenditures per mile over the period. Also consistent with this, and with the finding that the increased costs are due to increased inputs, not per unit input prices, we show that states construct more ancillary structures, such as bridges and ramps, and more wiggly routes in later years of the program. Controls for home value also account for a large proportion of the temporal increase; taken together, income and home value increases account for almost all the temporal change in costs.

The second hypothesis with which our data are consistent is the rise of "citizen voice" in the late 1960s and early 1970s. We use the term "citizen voice" to describe the set of movements that arose in the late 1960s—such as the environmental movement[9] and the rise of homeowners as organized lobbyists (Fischel 2001)—that empowered citizens with institutional tools to translate preferences into government outcomes (Altshuler and Luberoff 2003). Some of these tools, such as environmental review, were directly aimed at increasing the cost of government behavior, by requiring the government to fully internalize the negative externalities of Interstate construction. Other new tools, such as mandated public input, could yield construction of additional highway accoutrement (such as noise barriers), create delays, or increase planning costs.

If the rise of citizen voice is a key driver of costs, we anticipate an increase in costs after the 1970s, when these new institutional tools are available. We further anticipate that these tools are used most in locations with high incomes and high home values (see Brinkman and Lin (2019) for highway evidence). We find two pieces of evidence consistent with these predictions about the rise of citizen voice. First, we find that income's relationship to costs is five times stronger in the post-1970 era. This is consistent with the timing of the rise of citizen voice, which took flight in the late 1960s and early 1970s. Second, we find that the discussion in the *Congressional Record* around the Interstates was substantially more likely to involve environmental issues after 1970 and that these issues remained in heightened discussion after the passage of the National Environmental Policy Act in 1969.

Finally, there are other plausible explanations for which the evidence is either mixed or for which we have no data. We find mixed evidence on the impact of market concentration in the construction industry (a tighter conclusion awaits more data collection). Features of the soft budget construction and the repeated game aspect of the federal-state relationship may also be at play.

[9] 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).

Our work complements a large literature that concludes that enlarging transportation networks enhances growth. This literature focuses primarily on the benefits, rather than the costs. Economists find that the creation of the US Interstate highway system generated economic growth (Duranton and Turner 2012; Duranton et al. 2014; Yaffe 2019). Mechanisms for growth include knowledge spillovers (Agrawal et al. 2017), productivity (Fernald 1999; Holl 2016), and factor complementarities (Michaels 2008).[10] The conclusion that highway infrastructure creates economic growth extends to Great Britain (Gibbons et al. 2019), Spain (Holl 2106), and China (Faber 2014; Baum-Snow et al. 2016). Allen and Arkolakis (2014) examine the welfare benefits of highways and conclude that the construction of the Interstate system increased social welfare; follow-on work finds that potential highway improvements would also be welfare-improving. These estimates rest on a base on engineering costs. In contrast to this literature, which investigates the cost of infrastructure only inasmuch as it is useful as a comparison to its benefits, we focus directly on determinants of cost.

Our work also relates to an industrial organization that examines how procurement methods impact infrastructure costs. While this literature is very broad, extending to public-private partnerships and auction schemes, one strand focuses directly on government procurement and highway construction. Due to the difficulties in harmonizing data across states, these papers usually focus on procurement and spending within a state. For example, Bajari et al. (2014) use data from California to show that firms' plans for adaption add 7 to 15 percent to prices. Bolotny and Vasserman (2019) use similar data from Massachusetts to assess whether the state's system of scaling auctions is welfare-enhancing relative to lump-sum auctions. In contrast, our focus is on overall costs over the course of decades across the country and considering a variety of possible explanations for the large patterns we document.

This paper is organized as follows: Section 2 describes the history of the Interstate system. Section 3 describes our data. Section 4 documents the large increase in spending per mile over time. Section 5 tests hypotheses for this increase. Section 6 concludes.

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[10] See also Dills and Hernandez-Julian (2014) on highways and education, and Holtz-Eakin and Schwartz (1995) on productivity spillovers.

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. These are, in turn, the determination of routes, the timing of Interstate construction, the determinants of state funding, and federal construction requirements.

Route determination. The bulk of the highway system routing was determined in the 1940s and early 1950s, pre-dating federal government funding. The Federal-Aid Highway Act of 1944 established the initial 40,000-mile National System of Interstate and Defense Highways spanning the United States. Eisenhower envisioned the highways 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.

There was very little progress on Interstate construction 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 the federal government funded construction, the largest decisions over route existence and location were largely 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). We analyze funded miles through 1993.

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 (Michaels 2008). 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.

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.[11]

Funding. Funding for the system was overwhelmingly federal. Thus, at the state level, decisions about highway funding were largely about how to spend federal dollars, rather than about finding revenue for highway investments. The 1956 Highway Act set the federal government contribution for new highway construction at 90 percent of the 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 states' cost estimates for remaining miles 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 revenue for the Highway Trust Fund.

To better understand states' spending incentives, we provide more detail on 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

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[11] Based on periodic Interstate cost estimates that we inflate period by period to 2016 dollars.

[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/legsregs/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.

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 authorized each year an amount of money for Interstate construction on the basis of the estimated cost to complete the System, and on the funds available in the Highway Trust Fund. This money was then apportioned to the states.[13]

For all years after the first three,[14] states were apportioned funds in proportion to the estimated cost to complete their remaining planned Interstate mileage. Congress relied on state submissions of "Interstate Cost Estimates," 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.

Construction requirements. 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,[15] full control of access, minimum design speeds of 50-

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[13] A certain amount of this authorized money was deducted to pay for FHWA operations and research (FHWA 1983a).

[14] 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.

[15] 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,

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).[16] Mileage that received federal funding could not have tolls.[17] Congress also applied the 1931 Davis-Bacon Act to Interstate construction, requiring 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

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

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 identify the number of Interstate miles completed by state, county, and year from 1956 to 1993. Our data contain over 98 percent of the system's funded mileage built by 1993 (FHWA 1998). Though our analysis largely relies on state-level aggregates, our mileage data consists of one-mile "segments" of Interstate with precise geocoding 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.[18]

We complement these mileage data with our digitization of spending data from 1956 onward from the Federal Highway Administration's *Highway Statistics* series. 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

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.

[16] 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].

[17] 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).

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

maintenance, resurfacing, and other post-construction categories of spending. As we explain in Appendix B, 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, which means the year in which the segment is opened to the public. This generates a mismatch between the two data series, including 413 state-year observations (25 percent of observations) with expenditures but no completed miles. All else equal, this mismatch will lead to a decline in spending per mile over time, since spending pre-dates full mileage completion. Thus, the mismatch tends to bias estimates of spending per mile downward over time.

To more closely align the timing of spending with the timing of miles completion, we statistically evaluate the relationship between miles completion in year t and spending in year t and other nearby years. We use this relationship to produce an adjusted measure of Interstate expenditure. Specifically, we regress the number of miles opened in year t on spending in years t in {-5, -4, … , 10}. This regression (results in Appendix Table A1) associates a mile constructed in year t with 41 percent of spending from year t, 33 percent from year t-1, and 15 percent from year t-2. This pattern of spending over three years accords with more detailed opening data from the PR-511 data, showing that 72 percent of segments for which we observe the start date of construction and the open to traffic date were constructed in no more than three years. Because our spending data begin in 1956, and because we use a two-year lag, our data series begins in 1958. This reallocated spending measure is our primary measure of spending throughout the analysis.

Because miles are sometimes opened irregularly, there are a substantial number of observations with spending but no miles completed, yielding an undefined measure for spending per mile for some state-year observations. To ameliorate this problem, we group years into what we call “periods.” Our primary measure of a period is a six-year band, which evenly divides our

36 years of data. Our mutually exclusive six-year periods start with 1958-1963 and end with 1988-1993.

We also measure characteristics of the construction itself. We calculate the "wiggliness" (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 segments' number of lanes in the Highway Performance Monitoring System's 2016 road inventory (counting lanes in both directions).[19] We also measure the length of supporting highway structures associated with each segment of Interstate highway as the sum of Interstate bridge and ramp lengths.[20] To measure how slowly segments are built, a measure available for 3 percent of segments completed before 1966 and 80 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.[21]

We combine the expenditure and mileage data with a variety of other data described briefly below and detailed in Appendix A. We begin with variables that measure the physical and human geographic costs of construction. To measure population density, we use the Decennial Census population density of the tract in which the segment falls, using the value from Census year closest to the segment's opening date.[22] We measure the share of each segment built through wetlands, rivers, and other waters by the share of a segment's length built through these features using the US Fish and Wildlife Service's National Wetlands Inventory. We measure terrain steepness as the average slope within fifty meters of the path that a highway segment traverses.[23] For alternative specifications we rely on ecological categorizations. Data for the last two are from the USGS.

To measure demographics, we again rely on the Decennial Census. We measure median family income using state-level data. In addition, we calculate a "local" median family income as

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[19] 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.
[20] 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.
[21] 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.
[22] 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, also from the Decennial Census.
[23] 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.

the average of tract median income (if tract data are not available, county) reported in the nearest decennial Census for the segments through which the segment was constructed. We measure the median value of owner-occupied single-family homes using a similar local measure. We also include measures of political leanings and institutions that we detail in the appendix.

We measure labor and materials input prices from a variety of data sources. For national construction wages, we use the Bureau of Labor Statistics' hourly construction wages and the Bureau of Economic Analysis's measure of construction compensation. We also calculate state-level hourly wages from the Current Population Survey, 1962 to 1993, for construction industry workers and those whose occupation is construction. We use the BLS's Producer Price Index to measure materials prices (Carter et al. 2006; Bureau of Labor Statistics 2017).

To measure market concentration in the construction industry, we use data from the Census of Construction (years ending in -2 and -7 from 1967 onward) and from the County Business Patterns (1956, and 1971 to 1993). We collect the number of establishments in the detailed category of "highway and bridge construction" as well as the broader "heavy construction" and "construction" industries. Because we have no data for the 1950s and early 1960s, we view this data collection as incomplete.

Table 1 provides summary statistics on the subset of these measures used in our primary analyses. Here and elsewhere in this paper we report all dollar figures in 2016 dollars, using the CPI-U as the deflator. Table 1 reports the figures by each of the six-year periods in our data. The increase in spending per mile is evident, as is the decline in miles constructed in the two final periods.

4. Documenting Interstate Highway Spending Over Time and Space

We now turn to our first significant contribution: documenting the dramatic increase in the cost of building the Interstate system, as measured by spending per mile, from 1956 to 1993. We next show that the bulk of this increase persists, conditional on human and physical geographic determinants of construction cost and then date the timing of the increase. Finally, we present a summary measure for the cost increase to use as a baseline in exploring the impacts of covariates in Section 5.

We start our assessment of Interstate costs over time by looking at the US as a whole. Figure 1 presents national real spending per mile: total US Interstate spending in year *t* divided by total US miles constructed in year *t*. We present both annual data (lighter line) and a three-year moving average (darker line). 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. The majority of our analysis relies on state variation in spending per mile over six-year periods; we present this average in the line with dots.

4.A Is the Cost Increase Explained by Human and Physical Geography?

Per unit spending increases are of less broad policy concern if they are driven by the later construction of more physically difficult Interstate segments. Here we focus on whether states construct "easy" miles first. We test this explanation by dividing the idea of "easy" miles into geographically and politically easy construction. In this section, we consider geographically easy miles. 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 physically "easy" miles explains the increase in spending per mile, we assess whether the temporal pattern of the increase persists when we control for pre-existing physical and human geographic covariates and state fixed effects. Specifically, we estimate

$$\frac{spending}{miles}_{sp} = \beta_0 + \beta_{1,p}\, period_{\,p} + \beta_2\, \mathcal{G}_{sp} + \beta_3\, I_s + \varepsilon_{sp} \tag{1}$$

We use indices *s* for state and p for six-year periods. The periods we use are 1958-1963, 1964-1969, 1970-1975, 1976-1981, 1982-1987, and 1988-1993. (In future drafts we plan to assess whether our findings are specific to this periodization.) In this and all subsequent regressions, we weight by mileage opened in a given state-period. We do this to produce results that describe the average Interstate mile, rather than the average state.[24] We cluster standard errors by state. The primary coefficients of interest are the coefficients $\beta_{1,p}$, which report the average change in spending per Interstate mile across states.

To assess the role of physical constraints on spending, we include measures of human and physical geography, $\mathcal{G}$. We calculate these variables as the mean of those segments that open

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

in that period. For example, we calculate slope as the average slope for highway segments built in state s over the six-year period p. Because these controls are specific to the miles completed, they vary over time. Our main estimates include population density; slope; and wetlands, rivers, and other waters. To further correct for state-specific time-invariant attributes we include state fixed effects, I_s. These state fixed effects include, for example, state-wide time-invariant weather patterns or flood likelihood. To the extent that these state fixed effects also include policy choices, they over-control for the type of variation we are trying to omit.

We present results for coefficients $\beta_{1,p}$ in Table 2. The first column of Table 2 shows that the increase in costs shown in Figure 1 is statistically significantly greater than zero from 1970 onward. Miles constructed between 1976 and 1981 cost \$8 million more to build per mile than miles constructed from 1958 to 1963 (the omitted category). Figures for later periods are even higher (\$16 million for 1982-87 and \$26 million for 1988-93)—though there are relatively few miles constructed in these later years. The second column of Table 2 adds state fixed effects and shows that the temporal pattern of spending increase is relatively unchanged. We interpret the stability of the $\beta_{1,p}$ coefficients as evidence that the temporal cost increase is not driven by a shift in spending over time from low- to high-cost states.

The third and fourth columns of Table 2 repeat the first two columns but with controls for population density, the prevalence of water including rivers and wetlands, and the steepness of the terrain (measured by the average slope). Remarkably, the coefficient on the period dummy for 1976 to 1981 ranges only from a statistically significant 7.7 to 9.0 across all specifications; the 1970 to 1975 coefficient is always significant and ranges between 3.1 and 4.2. Later coefficients are similarly stable across specifications. The results also suggest that there is substantial signal in our geographic variables and measure of costs. In column (3) of Table 2, all three geographic variables are significant, at least at the 10% level, and are positively related to costs as expected.

To visually demonstrate the relative magnitudes of the period coefficients and their variation across specifications, Figure 2 shows them over time for two different specifications. The lighter line in Figure 2 shows results from the specification with state fixed effects only (Table 2, column (2)). The darker line in Figure 2 shows results when we additionally include the geographic controls (Table 2, column (4)). The figure makes it quite clear that the period coefficients are little changed with the inclusion of the geographic covariates. In fact, they are statistically indistinguishable. Figure 2's purple region shows the confidence interval for the second set of coefficients and demonstrates that spending in all six-year periods after 1970-1975 are statistically significant (at the 1 percent level).

To show the distribution of the change in spending per mile, Figure 3 shows spending per mile by state in the pre- and post-1970 eras—roughly dividing the data before and after the significant spending increase—conditional on pre-existing geographic features.[25] In particular, we regress spending per mile on the geographic covariates discussed above. We then use each state's pre-1970 miles-weighted residual as the starting point for spending per mile in each state. All residuals are normalized such that the smallest pre-1970 residual value is equal to zero. We calculate the final cost point, denoted with the arrowhead, as the miles-weighted sum of post-1970 residuals and period coefficients. (Appendix Figure A3 presents an analogous figure without controls for geographic characteristics. See also Appendix Figure A4.) We order states by the pre-1970 residual. The figure demonstrates that all but seven states required more dollars to build a highway mile post-1970 than pre-1970.[26]

In addition, the figure shows a dramatic increase in cost variation over time. The variance of costs increases by almost three times, pre-1970 to post-1970—from $44 million to $121 million. In the first era, all states but four have costs within $9 million per mile of each other. In the years 1970 onward, there is substantial cross-state variability in spending, even conditional on geography. Interestingly, this includes substantial within-region variability. This later-period 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. 2019). Appendix Figures A5i and A5ii show the data in map form.[27]

The large increase in per mile spending that we document is particularly surprising given two reasons to anticipate a decline. First, the mismatch between spending and mileage in our data pushes miles forward relative to spending. 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, decreasing our measure of spending per mile. As this surely occurs, our estimates may be a lower

[25] In our data, 60 percent of the miles are built through 1969 and 40 percent after 1969.
[26] These states are New Jersey, Louisiana, Maine, Idaho, Montana, North Carolina, and Alabama. The overall correlation in spending before and after 1970 is 0.013.
[27] In future related work, we plan a thorough investigation of this cross-state variation.

bound for the true spending increase. Second, many cost-decreasing technical innovations in highway construction have occurred since 1956. 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 the cost of reinforcing a bridge during construction by the 1980s by 30 percent (National Academy of Sciences 1984, p. 26). Laser-guided survey and excavation equipment have also improved productivity (Yates 1988, p. 71).

4.B. Quantifying and Dating the Increase

The rest of the paper focuses on the correlation between additional covariates and the temporal increase in spending per mile. It is therefore useful to have one summary measure of spending increase that we can compare across specifications. This raises three key questions: From which year do we date the spending increase? What are we interested in measuring? And how do we implement this decision?

To the first point, we choose 1970 as our primary cut-off date and compare spending per mile before and after this date. We choose 1970 because Figure 2 shows that the 1970-1975 period indicator is the first to be significantly different that zero—that is, the first period to show a sustained cost increase above costs in 1958-1963.[28]

When considering an increase in spending per mile, both the level and the trend may be of interest. In this work, we focus on how the cost level changes over time. The level is most easily interpretable, and it is of most direct policy interest. Changes in trends are also of interest, but they are more difficult to interpret and they also require more data to estimate. For these reasons, our analysis focuses on the average change in the level of spending per mile before and after 1970.

We create a summary measure of the post-1970 change in spending per mile by comparing the mile-weighted average of the period coefficients before 1970 with the mile-weighted average coefficients in 1970 onward. Specifically, our summary measure of change in spending per mile over time is T, defined as

$$T = \left(w_{1993}\beta_{1\_1993} + w_{1987}\beta_{1\_1987} + w_{1981}\beta_{1\_1981} + w_{1975}\beta_{1\_1975}\right) - \left(w_{1969}\beta_{1\_1969} + w_{1963}0\right) \quad (2)$$

[28] We tried a battery of more sophisticated econometric tests, but the data are sufficiently noisy that they struggle to distinguish any clear inflection point.

in which w_p is the six-year period's share of miles (relative to the total miles built in either the pre- or post-period) and coefficients $\beta_{1,p}$ and weights w_p are indexed by the endpoint of the period. That is, we subtract the mile-weighted mean of costs before 1970 from the mile-weighted mean of costs from 1970 onward. Recall that all coefficients are relative to the first time period, which ends in 1963.

Using this framework, we re-state the results from Table 2 in the first panel of Table 3. In the most basic specification, including only period fixed effects, the average increase in spending per mile, *T*, is \$6.8 million. In the final specification, which we will use as our baseline for the rest of the paper, this figure is \$7.3 million. Recall (Table 1) that spending per mile in the first two periods is roughly \$8.5 million per mile, so this is an almost-doubling.

4.C Findings Robust to Variations in Covariates and Sample

A natural concern with this approach is that it depends heavily on the specific geographic covariates chosen or their functional form. Panel B of Table 3 shows that our findings are robust to polynominal specifications of the geographic covariates. In addition, the summary measure of spending change, *T*, is invariant to controls for the average share of segments that pass through a dozen types of ecoregions.

One might also be concerned that the imbalanced nature of our sample, or the large increase in spending in the final period may drive these findings. Panel C of Table 3 shows that spending increase is qualitatively identical, regardless of whether we use a balanced panel, drop the last period, or do both simultaneously.

5. Explanations: What Might Drive Infrastructure Costs?

The remainder of our paper focuses on the validity and magnitude of explanations for the increase in spending per mile over time, focusing on a variety of commonly-stated potential drivers of infrastructure costs (e.g., McKinsey Global Institute 2013; Gordon and Schleicher 2015). We begin by describing how we assess the impact of covariates on the temporal change in spending. Next, we describe four hypotheses that fail to find support in the data we have collected. We then turn to two explanations that account for a substantial amount of the temporal change. First, demand for highway attributes is such that increases in income yield more expensive highways. Second, the rise of citizen voice in the development process in later years yields more expensive highways. We conclude with additional possible explanations for which data are limited, including decreased competitiveness in the construction sector. While our ultimate goal is to shed light on causal drivers, we view the work in this section as suggestive and predominantly correlational, assessing how well the evidence is consistent with plausible hypotheses.

5.A. Methodology

To consider the relationship of covariates with the temporal pattern in Interstate highway spending, we add covariates $C_{s,p}$ to equation 1, denoted as below.

$$\frac{spending}{miles}_{sp} = \beta_0 + \beta_{1,p}\, period_t + \beta_2\, \mathcal{G}_{sp} + \beta_3\, I_s + \beta_4\, C_{sp} + \varepsilon_{sp} \quad (3)$$

To avoid issues of scaling, we normalize all non-geographic covariates to be mean zero and standard deviation one. Our focus is on the measure T, based on coefficients $\beta_{1,p}$ (see Equation 2) that capture the average increase in spending per mile after 1970. In other words, we are interested in the correlation between the variation in C and the temporal increase in spending per mile captured by $\beta_{1,p}$. Note that while we focus on the change over time, identification comes from cross-state variation.

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

Four hypotheses for the increase in spending per mile appear largely inconsistent with our data. We review each in turn, beginning with two findings worth emphasizing from the previous section.

Geographically difficult segments built later. As we discussed in the previous section, the explanation that segments that are geographically more difficult in observable ways were built later is not consistent with the data.

Time-invariant features. Because the temporal pattern in spending from Table 2 is roughly invariant to the inclusion of state fixed effects, anything fixed by state—let alone at the national level—but constant over time is insufficient to explain the increase in spending per mile.[29] Such fixed state characteristics could include, for example, any time-invariant aspects of the institutions governing a state's Department of Transportation.

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 common law protections allow individuals and small groups to slow down development with costly lawsuits and other legal challenges. This explanation may well hold weight in an international comparison. In our setting, evidence for this claim is weak. The United States is and was a common law country, and things that do not change should not cause large changes in costs. As we explore later, however, it is possible that common law could have interacted in important ways with other trends to yield cost increases.

Labor, materials and land input prices. Increases in labor or materials prices are very straightforward explanations for an increase in spending per mile. For example, a sustained increase in the price of concrete should surely drive up Interstate costs.

To assess whether input prices are a key driver, Figure 4 presents summary statistics. The figure indexes all values to 100 in 1961. The figure shows Interstate spending per mile (based on the average of six-year period data), along with national measures of labor and materials prices.[30] (See data section for more details on sources.) We show both national construction hourly wage (BLS) and construction compensation data (BEA).[31]

The difference in the temporal pattern between our measure and these price indices is striking. By the end of the 1960s, the figure shows a small increase in spending per mile, commensurate with increases in labor prices. After this, the series diverge. Spending per mile increases, while labor and materials prices are roughly unchanged in real terms at the end of the sample. While construction compensation increases more than wages (see Swei (2018)), the

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[29] Of course, it is possible that fixed state characteristics impact construction costs, even if inclusion of state fixed effects has little impact, if the extent of different fixed characteristics that increase costs is negatively correlated across states. For example, if there are two variables, A and B, both of which increase construction costs, and half of states have more of A and less of B, and the other set of states have the reverse, then state fixed effects could have little impact at the same time as fixed characteristics impact costs. We cannot rule out such a possibility.

[30] 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.

[31] Swei (2018) argues that the increase in construction compensation has bypassed increases in construction wages.

differences are miniscule relative to the increase in spending per mile. In addition, even large increases in the use of overtime would be insufficient to explain much of the temporal increase.

We consider prices more formally in our regression framework, which requires state-level variation in input prices. While we do not have state-level variation in materials input prices, we use the Current Population Survey to create a measure of wages both for workers in the construction industry and workers who list construction as their occupation (1962-1993).[32] As we do for all variables for which we lack data in earlier years, we take the earliest year of data that we have, and impute that value backwards, so that we do not have missing data.

Table 4 reports results. Our baseline estimate (Table 2, column 4) is in column 1 for reference. The remaining columns present results for different wage measures. Regardless of measure, we find that the summary measure of temporal change in costs, T, barely moves. These estimates of T are always statistically significantly greater than zero and always statistically indistinguishable from the baseline T. Both coefficients on CPS wages are small and indistinguishable from zero.

Thus, the explanation of increasing labor and material prices is likely insufficient to explain much of the observed increase in spending per mile. Furthermore, because the price of labor is roughly flat over the sample, a Baumol cost disease-type explanation, in which high priced labor accounts for an increasing share of expenditures, is also not consistent with the data (Baumol and Bowen 1965).

Figure 4 also points out that the divergence between the price of the underlying components of highway construction—labor and materials—and overall highway costs 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 the 1939 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

[32] Because early years of the CPS aggregated smaller states together, we use this aggregation throughout for consistency.

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.[33]

These "more inputs" could be more units of labor and materials to construct such things as sound barriers or longer bridges. Similarly, any type of construction that yields a less disruptive route, or less disruptive construction techniques, more parks, or more noise walls should increase cost.

The final main input into highways is land, and an increase in the price per unit of land could surely drive increases in spending over time (Garnett 2006). To assess whether the per unit land expenses were increasing over time, we digitized additional data from 1961 to 1984 that divide expenditures by type: construction versus preliminary engineering (PE) and right of way (ROW).[34] The data show that the share of spending on right of way and planning costs is fairly small, less than 18 percent of expenditures over the entire period and never more than 25 percent in any given year (see Appendix Figure A6). 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

[33] 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).

[34] 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.

and planning costs contribute to rising construction costs—since their share drops only modestly over time as costs go up—they cannot be the main driver of spending increase.

In future work, we plan to use data on assessed land value from the Census of Governments from 1956 to the present from the Census's Taxable Values reports. Assessed values are subject to some concern, but to the best of our knowledge they are the only long-run national data available and have been used by others (Greenstone and Moretti 2004).

Federal Interstate standards. Finally, with the exception of increased capacity requirements,[35] we know of no large changes in federal Interstate construction standards that increased spending per mile. After an extensive search, we are unaware of any other substantial changes in design standards required by Federal Interstate guidelines that could have led to substantially increasing costs over time,[36] 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.

5.C. Consistent Explanations

We now turn to two related and overlapping explanations for spending increase that do find support in the data. These are that demand for more expensive Interstate features increases with income, and the rise of citizen voice in government decision-making.

5.C.1 Demand for Interstate Highways Increases with Income

Higher-income actors—or, more broadly, those with greater resources—may demand more expensive highways for at least two reasons. First, demand for most goods increases with

[35] 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 is a good proxy.

[36] 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.

income or wealth. Second, apart from their willingness to pay for more expensive highways, wealthier actors may have stronger voices in the political process to demand more expensive highways that reflect their concerns. Between 1956 and 1993, total personal income per capita doubled in real terms (US Bureau of Economic Analysis 2019). Thus, we may anticipate that rising real income yields increased demand for more expensive highways—recalling that the total miles of the system is roughly fixed. Highway features responding to local citizen concerns that could make them more expensive could relate to either the process or the output of construction. As to process, highways can be constructed in a way that is slower and more deliberative or uses techniques that are less disruptive to surrounding to communities. As to output, highways can have noise walls, be built in trenches to reduce noise, have overpasses with parks, or be built through more expensive routes to reduce disruption to historical sites, the environment, or neighborhoods.

This hypothesis is consistent with our findings as shown in Table 5. The inclusion of real state-level median family income in Equation (3) decreases the temporal change in spending by mile by roughly half. In particular, only the period coefficients after 1982 are now significantly different from zero. We find in column 2 that a one standard deviation (about $10,000) increase in state-level median family income (conditional on state fixed effects and period fixed effects) is associated with a cost increase of $5 million per mile. (This is consistent with a large literature in environmental economics that shows that demand for air quality and water quality increases with income (Kristöm and Riera 1996; Ebert 2003).) Thus, the combination of this strong relationship—estimated using cross-state, cross-time variation—between costs and income and the overall increase in income over time drives the period coefficients in later years toward zero, as income explains more of the variation. Similarly, if homeowners are concerned about Interstate construction because it affects the value of their largest uninsurable asset, then variation in home value should explain some of the temporal increase in spending per mile. Adding a control for real median home prices, measured as the state-year average of real county home prices through which segments lie, reduces the period coefficients by 60.5%. And a one standard deviation ($28,222) increase in home values is related to a $6.34 million increase in spending per mile.

Recall from earlier that a relatively small share of spending goes to land acquisition and that this share, if anything, decreases over time. Overall then, 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 the mechanism through which increased housing prices is related to increased costs is primarily through construction costs rather than land acquisition costs.

Taken together, the inclusion of both real income and real home value nearly eliminate the increase, as we show in Figure 7, resulting in a striking 99% reduction in the period summary measure.

It is notable that housing prices have explanatory power beyond incomes. This could be for a few reasons. First, income is a flow, whereas housing is a stock; either could impact demands for more expensive highways. Second, housing is more tied to the particular location where highways are being built than income is, so greater housing prices—which increase the stakes for the impact of highway development—may generate concern about highway development that income does not. Third, both measures are different and imperfect proxies of resources that could lead to more political voice, and two imperfect proxies for one thing can both have explanatory power.

If citizen demand drives spending increases through higher quality, there should be either some physical manifestation of this quality or an increase in delay or planning costs. Our ideal measure for this would be detailed attributes of highway construction time at the time of construction. Most highway attributes we do not observe; we do not know where there are noise walls or highway trenches or where there was more community collaboration. But we do observe a few variables. What we observe is some attributes of highway miles that are within the scope of state choice: time from beginning to end of construction, and, as of 2016, wiggliness of highway miles, and the quantity of Interstate capital employed via ramps and bridges.[37] Figure 5 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 (see this figure condition on geographic covariates in Appendix Figure A7).

The top right panel shows the average wiggliness (formally, tortuousity) of a highway mile by year. We calculate this value as the ratio of the true length of each of our observed one-

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[37] 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, while this trend may drive up costs over time, it would not show up in our ramp data.

mile segments divided by the straight, as-a-crow-flies distance between the segment's endpoints. Entirely straight segments have a value of 1, and the measure increases when segments are curvier. Greater wiggliness 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. State decision makers could make highways curvier to 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. However, the magnitude of change in this measure is quite small.

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. The horizontal axis value here is the year that construction begins, not the year that miles open, different 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. The data start later here because over 90 percent of the data 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 of segment opening. These capital investments may mitigate Interstate impacts via bridges and elevated highways, or to increase commerce, such as with more frequent off-ramps. 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.

The regression evidence in Appendix Table A3 shows that these measures are related to higher costs. We combine bridges, overpasses, and ramps into "structure density," but we emphasize that these are only a portion of possible structures; for example, we do not capture tunnels, noise walls, or sunk highways. Column 1 suggests that an additional "structure" per mile of Interstate is associated with an increase in spending of $19.15 million.[38] Column 2 suggests that an increase in wiggliness equivalent to the average change we observe from the 1960s to the 1980s—a change of about 0.01—is associated with an increase in spending of $9.64 million. Including both measures in column 3 modestly reduces our summary cost measure, accounting for 17 percent of the cost increase. Including other features that could be related to more expensive highways but on which we do not have data would presumably explain yet more of the cost increase.

Finally, to help understand the mechanism involved, we compare the impact of state versus local income. Recalling that state governments and not local governments fund a portion of the Interstates, if greater resources to finance construction drive the relationship that we see, then we should see the relationship driven by increases in state-level income. If, instead, what drives the relationship is that residents of localities demand more expensive highways to be responsive to their concerns, we should see the relationship driven by increases in local-level income. Specifically, we create a state-period measure of "local" income by taking the miles-weighted state-period average of real tract median income for tracts where highway segments are constructed. This is a measure of income where highways are constructed, rather than an overall measure of state income.

We test this hypothesis in Table 5, column 5. Our summary measures of temporal change in spending per mile, T, is slightly smaller (2.95), conditional on local income, than conditional on state income (3.07). When we include both measures in the same equation (column 6), T drops to 1.1 and is insignificantly different from zero, explaining 85% of the baseline period summary measure. But the strength of the relationship between local income and costs is much larger (by about 62 percent) than that of state income, and only the coefficient on the local income measure is significant. This finding is consistent with both factors being important, but with rising local demand being more determinative of cost outcomes than greater state resources.

[38] Recall that right-hand side variables have been standardized by their standard deviation. Dividing the coefficient of 6.13 by the standard deviation of 0.32 yields this result. We perform the same arithmetic for wiggliness.

5.C.2. Increased Citizen Voice

While it seems plausible that increased demand due to increased income explains part of the overall increase in spending per mile over time, there are reasons to believe that spending per mile increases beyond what would be associated with this overall increase in income.

A large literature suggests that in the late 1960s and early 1970s, a combination of social movements, legislation, and judicial doctrine significantly expanded the opportunity for citizen involvement in government writ large. For example, Altshuler and Luberoff (2003, p. 22) cite the rise of the environmental movement, the civil rights movement, and the increase in homeowner power as the three pillars of this new influence (see Fischel (2001) on homeowner power). We call this confluence of factors "citizen voice" and provide suggestive evidence on its importance in spending per mile (see Glaeser and Ponzetto (2017) for a similar argument).

We date the increase in citizen voice to the late 1960s, when homeowners became more organized, and when the legislative bargaining for the 1970 passage of the National Environmental Policy Act (NEPA) began in earnest. These movements gained 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 specific legislation. The legislation under which citizens could bring suit are also creatures of this same time period. Two prominent examples are NEPA, which requires environmental impact reviews for projects with significant federal funding, and the National Historic Preservation Act of 1966, which prevents development on national historic sites. Other key legislation includes the 1973 Endangered Species Act, the 1972 Clean Water Act protecting wetlands,[40] and a variety of other federal legislation making it more difficult to develop on public lands. In addition, many states also passed their own statutes on environmental review.

Citizen organizations flourished at the same time. This legislation 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

[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.

(Brinkman and Lin 2019; Swift 2011). For example, the Environmental Law Institute was founded within two weeks of NEPA's passage in 1970 (Environmental Law Institute 2019).

There are multiple reasons that these changes could increase the cost of building infrastructure. The first is the cost of environmental review: environmental review statutes require that projects involving significant government funds conduct environmental reviews. Litigation is costly, too. However, as we discussed above, 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 direct contributor to costs. Second, the environmental review statutes or public comment requirements 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 increased spending: citizen voice leads to more expensive routes and structures to respond to local concerns.[41]

5.C.2.(a) Illustrative Example: Interstate Construction in Suburban Detroit

To illustrate how citizen demands, moderated by more responsive institutions, could increase costs, we give the example of a 28-mile stretch of I-696 in Detroit's northern suburbs. 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).[42] The earlier two legs faced little resistance and cost far less than the final leg, which faced significant resistance. The first leg was completed in 1964

[41] We also consider other measures of citizen voice, which do not considerably change the period summary measure. 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 correlated with costs, but causes little change in the summary measure of change (Figure 8). A state-level measure of the number of land use court cases per capita from Ganong and Shoag (2017) does not have a statistically significant correlation. The Wharton Land Use index, a time-invariant 2006 measure of how much local jurisdictions restrict development, has a statistically significant relationship interacted with the post-period, but also has little impact on the summary measure of change. However, none of these measures—either interacted with the post-period or not interacted—appreciably changes the period summary measure, which suggests that land use law itself may not be an important mechanism driving costs.

[42] 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.

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).[43] 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, an 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.

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.[44] 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).[45] 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).[46]Apart from the rabbi, these features are shown in

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[43] Data are from Baum-Snow (2007). Construction began in 1969-71

[44] 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.

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

[46] *Id*.

Appendix Figure A8. Also, note that none of these amenities are reflected in the structures data that we have, suggesting plausible mechanisms for how citizen voice could have manifested itself in costs.

5.C.2(b) Quantitative Evidence

In this section, we suggest and examine two patterns in the data that should hold if the increase in citizen voice drives higher Interstate construction costs. First, the covariates we hypothesize are measures of the strength of citizen voice should increase their effect on the temporal pattern of spending after 1970. Second, politician rhetoric should change in about 1970 to privilege the discussion of citizen voice concerns; we test this with text from the *Congressional Record*.

5.C.2(b)(i) Changes in the Impact of Covariates over Time

The work above shows that increases in income, particularly local income, can explain a large part of the temporal increase in Interstate spending per mile. However, the citizen voice hypothesis makes a more nuanced claim: that the institutions available to voice concerns about construction after 1970 allow for a magnified impact of income increases after roughly 1970. To assess whether the data are consistent with this claim, we modify our estimating equation to allow the covariate of interest, $C_{s,t}$ to have an additional relationship with spending in the years 1970 and onward:

$$\frac{spending}{miles}_{st} = \beta_0 + \beta_{1\_t}\, period_{\,t} + \beta_2\, \mathcal{G}_{st} + \beta_3\, I_s + \beta_4\, C_{st} + \beta_5 C_{st} \cdot after_{st} + \varepsilon_{st} \quad (4)$$

The variable $after_{st}$ takes the value 1 in any period from 1970 onward (that is, in any of the four later periods). Thus, β_5 measures whether the relationship between covariate C and spending changes in the years following 1970.

Our hypothesis about citizen voice suggests that when C is income, β_5 should be positive. We report results in Table 5, column 7, and the interacted coefficient appears in the last coefficient row. Comparing the column 7 results to the uninteracted result in column 5 shows that the post-1970 income is the key driver of the relationship with spending per mile. The coefficient on income pre-1970 is only 1.19 (and is not significant), whereas the combined coefficients on income post-1970 are almost five times as large: 5.71 (and highly significant). These findings are consistent with the hypothesis that the technology—the statutes, judicial doctrine, and citizen organizations—for translating citizen "demand" for attributes (such as litigation or alternative routes) fundamentally changed after 1970.

We see a similar phenomenon with the highway attributes themselves. We also find that structures and wiggliness are more related to higher costs after 1970, with a one standard deviation increase in the measure additionally related to $4.23 million per mile for structures and $5.02 million per mile for wiggliness after 1970 (results available upon request). The result that these become costlier suggests that citizens may be demanding more expensive types of structures and route modifications over time.

5.C.2(b)(ii) Text Evidence on Political Responsiveness

The previous subsections show a variety of empirical evidence consistent with the hypothesis that increased citizen voice leads to greater spending per mile. If this hypothesized mechanism is important, it should be driven in large part by the behavior of local elected officials responding to their constituents. To measure the thinking of elected officials, we turn to the *Congressional Record*, which contains "all text spoken on the floor of each chamber of Congress" (Gentzkow et al. 2018).[47] (Ideally, we would use text from all local newspapers as well. To the best of our knowledge, no such corpus exists.)

To evaluate the topics that discussion of the Interstate engenders, we prepare each Congressional speech by omitting all stop words (e.g., "is," "and", "the") and by reducing all words to their stems (e.g., "environ" from "environmental," "environment," etc).[48] We then extract the 100 words before and after each occurrence of the word "Interstate" in the Congressional Record from the 79th Congress (1944-1945) through the 103rd Congress (1993-1994). From these 201-word strings, we exclude all strings that include the two-word pair "Interstate commerce," which has a specific constitutional meaning not related to our topic of study. These data then allow us to examine changes in speech around the Interstates from 1945 to 1993.

Figure 6 presents the prevalence of the word stem "environ" within 100 words of the word Interstate by Congress, divided by the number of times the word "Interstate" appears in

[47] These data were cleaned and assembled by Gentzkow et al. (2018). See https://data.stanford.edu/congress_text for further details on the data creation.
[48] We use the tm_map package for R and rely on its database of stop words and stemming.

each Congress.[49] A clear pattern emerges: before the discussion in advance of the passage of NEPA in 1970, "environ" is used sparingly in conjunction with "Interstate." Usage around "Interstate" peaks in the session where the law is passed, but remains elevated afterward for the entire period of analysis. Thus, the evidence from politician behavior is consistent with heightened attention related to issues of citizen voice.

5.D. Cost Drivers with Limited or No Affirmative Evidence

There are many other potential explanations for which either our data do not provide supportive evidence or for which we do not have appropriate data. We list them briefly here.

Construction Industry Market Concentration. Basic economics suggests that increased market concentration may cause an increase in Interstate spending per mile. And the field has a renewed interest in industrial concentration. De Loecker, Eekhout, and Unger (2018) produced data on the markups in the general construction industry and find a modest change between the 1960s and 1980s. A literature specific to state construction procurement offers evidence that builders may be able to manipulate their contracts in ways that increase spending (Bajari and Ye 2003; Gil and Marion 2013; Mochtar and Arditi 2001; Miller 2014).[50] However, to the best of our knowledge, whether these practices are associated with increasing spending over time remains an open question.

We currently rely on two similar data sources (Census of Construction and County Business Patterns) that are giving two very disparate answers. We view this claim as a work in progress until we are able to collect establishment data from the 1950s and 1960s.

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 Interstate construction may require the coordination of many different levels of government that may have difficulty efficiently cooperating (Gillette 2001). While we cannot make a US-Europe comparison, we can assess whether greater fragmentation within the United

[49] A small data note: if "Interstate" appears more than once within a 200-word phrase, we re-weight our frequency calculation so that a word near "Interstate" never counts for more than one. This happens infrequently.

[50] 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.

States is associated with higher costs. If this hypothesis is true, controlling for the number of governments per capita should mitigate the increase in spending measured by *T*. We find that the temporal change in spending is little affected by inclusion of the number of governments per capita (Figure 8). However, we are concerned that we may not be measuring the relevant jurisdictions—we measure all local governments as collected by the Census of Governments. It may be that local jurisdictions not surveyed (as many types of special districts are not) or other governmental equities (federal equities in local lands) are key.

State government quality. It is plausible that government quality—for example, the effectiveness of government bureaucrats in contracting for construction services—is linked to Interstate spending per mile. To test this hypothesis, we examine how two measures of government quality impact *T*: the state bond score[51] and the number of convictions of state officials per capita.[52] Neither of these variables considerably reduces *T*. We take from this that these measures of government quality are not important drivers of infrastructure cost increases. We leave open the possibility that other measures we have not used may be more able to explain the change.

Increased use of labor. We know from Figure 4 above that the price of construction labor has been fairly flat over the period, so labor prices are not an explanation for increased spending. However, usage of more labor per Interstate mile could certainly increase spending. Some claim 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). Unions can demand such work rules in part because "project labor agreements" (PLAs) signed by states require union labor. However, for PLAs to drive the spending change we see, they would need to become more important at the same time that the power of unions has, if 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

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[51] To quantify states' S&P bond rating, as a measure of the quality of their fiscal governance, we measure a AAA rated bond as 1, 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. (Thank you to Lang (Kate) Yang for sharing these data.)

[52] We also use an index of corruption based on a 1999 state-level survey of statehouse reporters (Boylan and Long 2003), but as this measure is time-invariant we use Equation 4 and interact it with the after coefficient. We find no impact on *T*.

abundant. All of these hypotheses argue for measurement of the quantity of labor input, which we do not observe.

As a proxy, we estimate Equation 3 with controls for variables that measure the likelihood that states mandate or encourage higher quantities of labor usage. We use unionization rates and the presence of "right to work" laws that make unionization more difficult, to account for the strength of the labor movement. We use the presidential Democratic vote share as a proxy for 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.[53] None of these explanatory variables appreciably decreases the period summary measure, including when interacted with being after 1970. However, because we have no direct measure of labor quantity, we are reluctant to firmly exclude this hypothesis.

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.[54] Because of the mechanical relationship between spending and miles, we have been unable to devise an adequate test for this hypothesis.

Soft budget constraint/end of repeated game. The problems of soft budget constraints, in which a budget constraint given by one level of government is exceed by another level of government without consequence for the second level of government, has been subject to substantial work in economics (Kornai 1980). The parallel here would be that states exceed federal Interstate spending and are reimbursed for the amount exceeding the amount allowed. To the best of our knowledge, this was not a systematic feature of state behavior in the program, perhaps because the federal government has many other levers with which to punish state misbehavior.

The economics literature also discusses repeated games as a means of establishing social norms. Using this framework, it is possible to hypothesize that transportation officials in the infancy of the program perceived a repeated game in which there were future incentives for

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

[54] One measure that might seem an obvious way to test this explanation—the number of Interstate miles a state builds in a given period—is, in our opinion, so problematic as to be worthless because of the way highway miles were funded. Since the Federal government funded miles based on the share of total spending remaining, if a state is in a period in which it is building expensive miles, it must build fewer miles to stay within the budget.

current economizing behavior. However, as the end of the repeated game neared—specifically the end of the Interstate program—the future benefits from cost containment by states may have waned, and states may have believed that the federal government would complete the Interstate system regardless of behavior. Alternatively, norms of thriftiness could have broken down over time. These are interesting and plausible hypotheses for which we have not developed empirical tests.

Procurement practices. A large economics literature finds that procurement practices matter for spending. Unfortunately, we were unable to find data on procurement practices. We think that this is fruitful area for future research.

6. Conclusion

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 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. Instead, our results suggest that higher per mile spending is driven by the use of more inputs, such as labor or capital. These greater inputs may result in the construction of Interstates with additional features such as noise walls. The results also 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 rising incomes and the institutional changes leading to increased citizen voice. In particular, the rise in income and housing prices nearly entirely statistically explains the rise in construction costs—though not primarily via increased land costs. These findings on costs, while suggestive, are not causal. They also do not speak to potentially varying benefits of highway construction over space and time. There are malign interpretations—about increased influence of NIMBYism—and benign interpretations—about internalizing externalities of highway construction—to the explanations, but we cannot say at this point which type of interpretation more closely fits the data. In any case, this provocative finding that rising income and housing prices statistically explain the construction cost increase demands further research on mechanisms, to help answer this normative question. We hope that our paper helps point in a direction toward considering whether the benefits of the increased spending justify the substantial costs, and how to reduce spending as appropriate.

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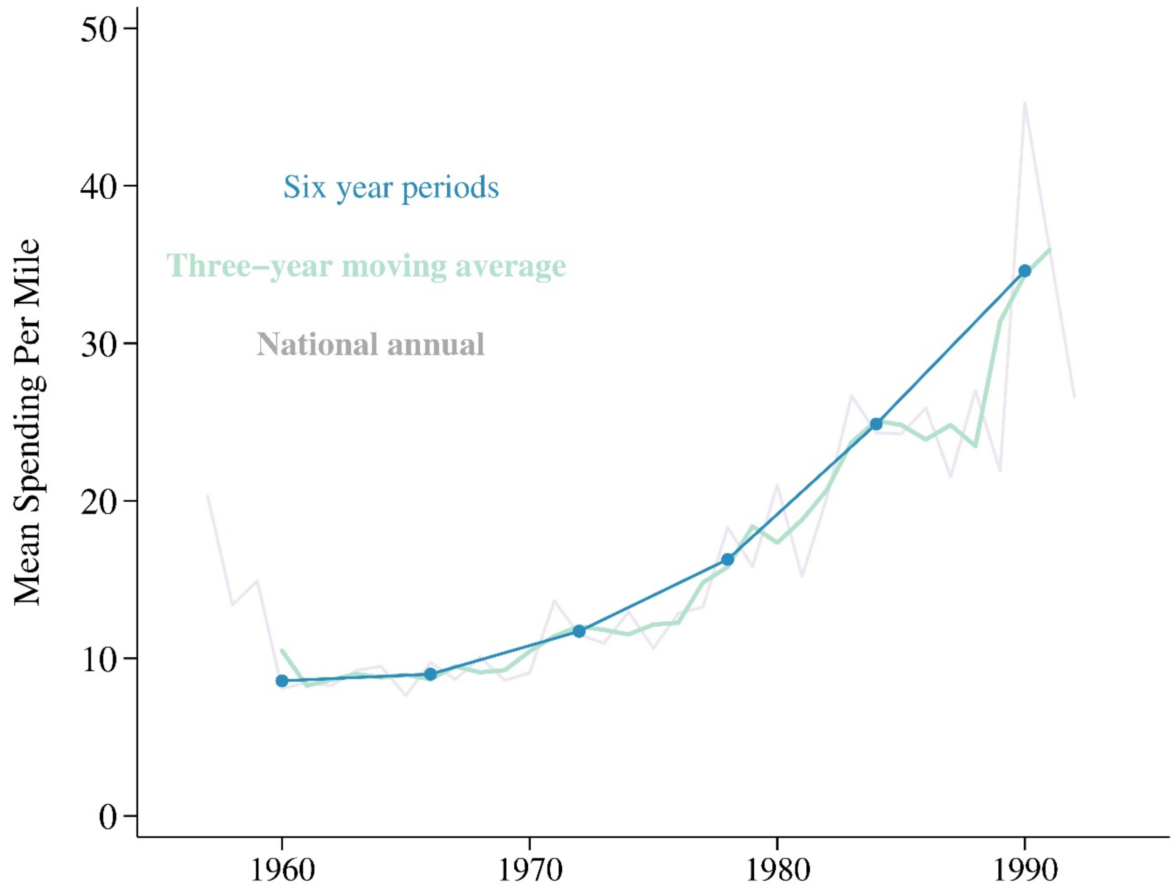
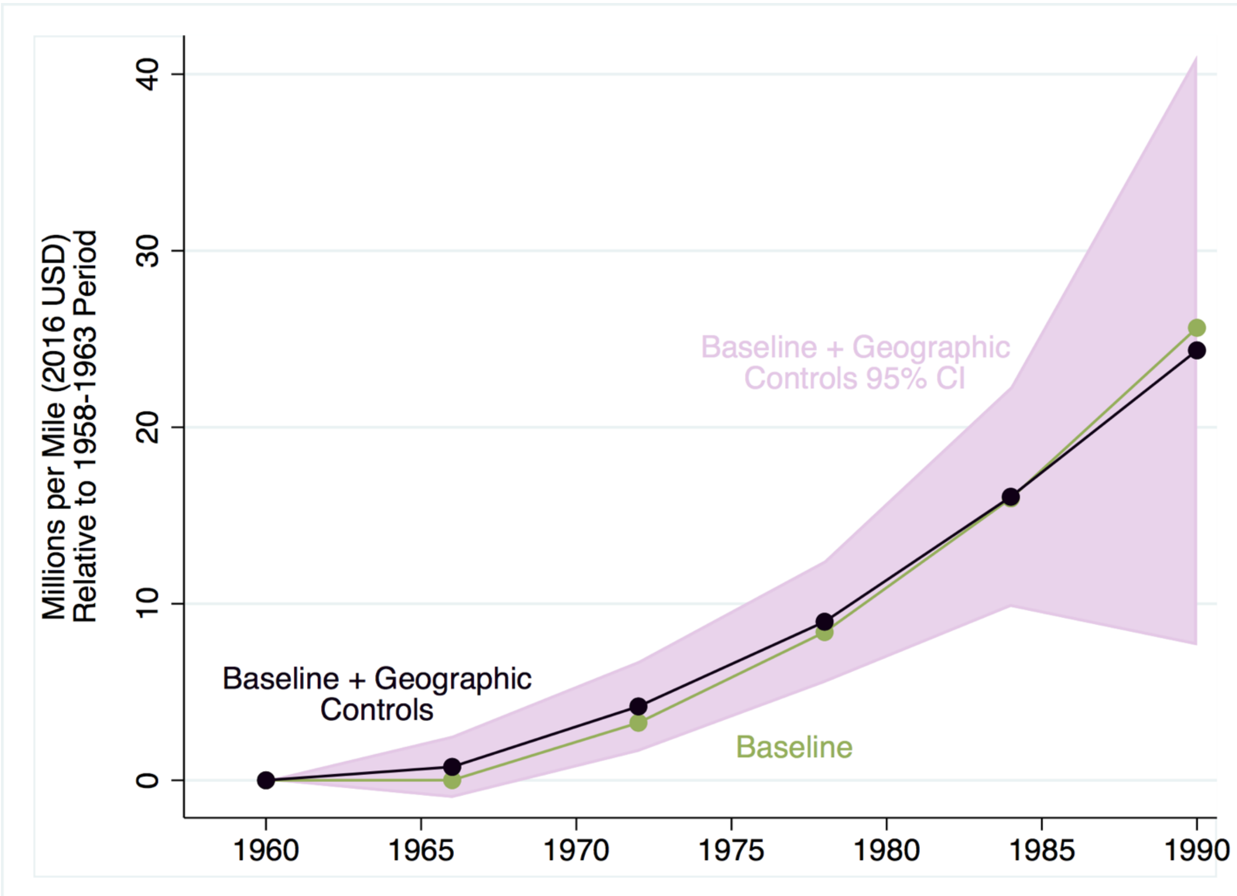
Figure 1. Interstate Construction Spending per Mile Increases Over Time (2016 US Dollars)



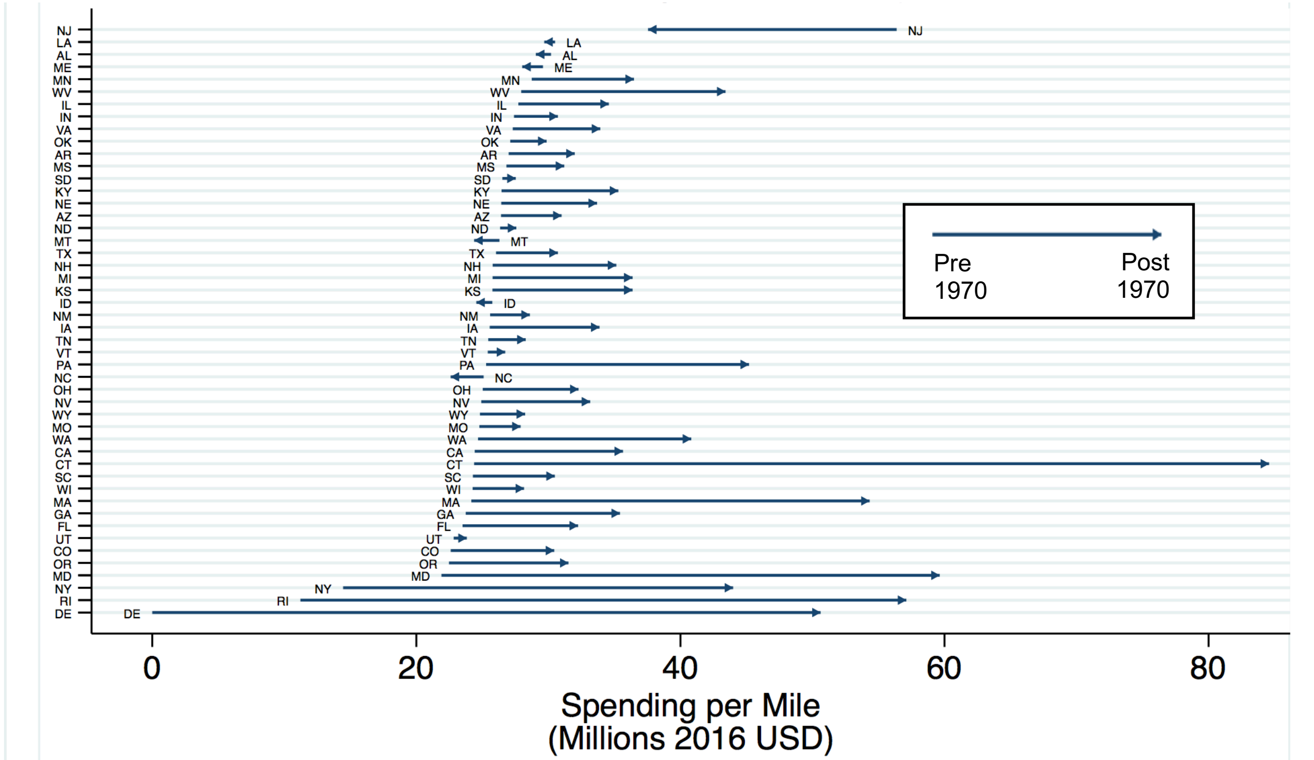
Notes: This figure reports national spending per mile as the sum of total spending in a given year divided by miles completed in that year. We calculate the 3-year moving average from this figure. The line with the blue dots shows the miles-weighted average of state data grouped in six-year periods as discussed in the text. For purposes of presentation, we omit 1993, which is a very high outlier and has very few miles.

Figure 2. Interstate Spending Conditional on Physical and Human Geography Increases Over Time



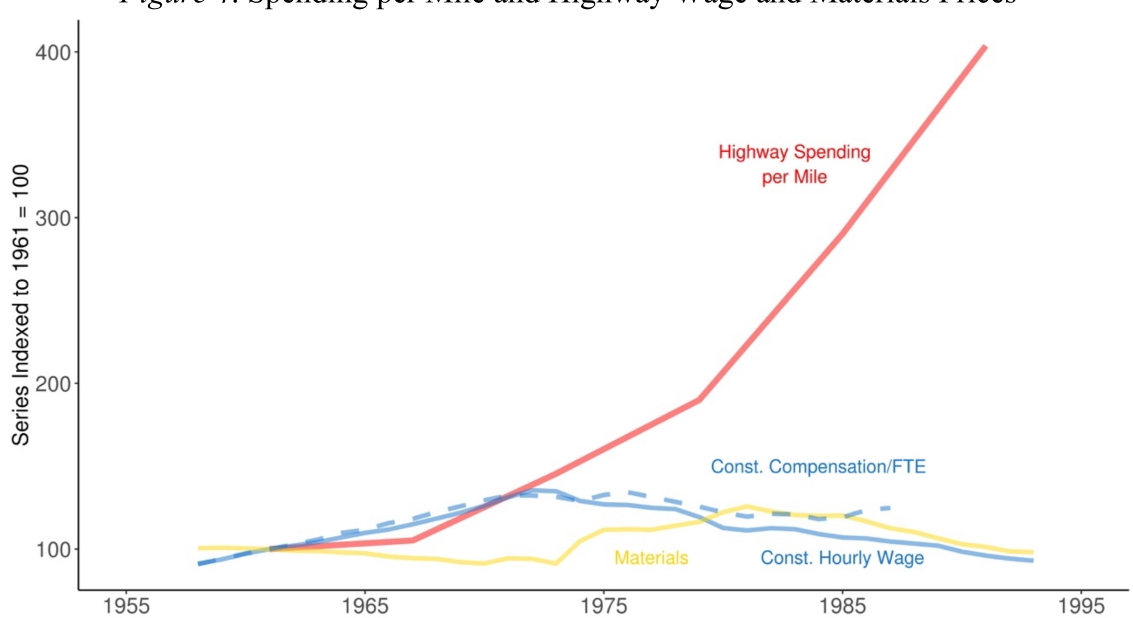
Notes: Points shown are the estimates for indicators for each time period in Table 2: "Baseline" is column (2) (only period effects and state fixed effects) and "Baseline + Geographic controls" is column (4) (period effects, state fixed effects, and geographic controls).

Figure 3. State Spending per Mile: Before and After 1970



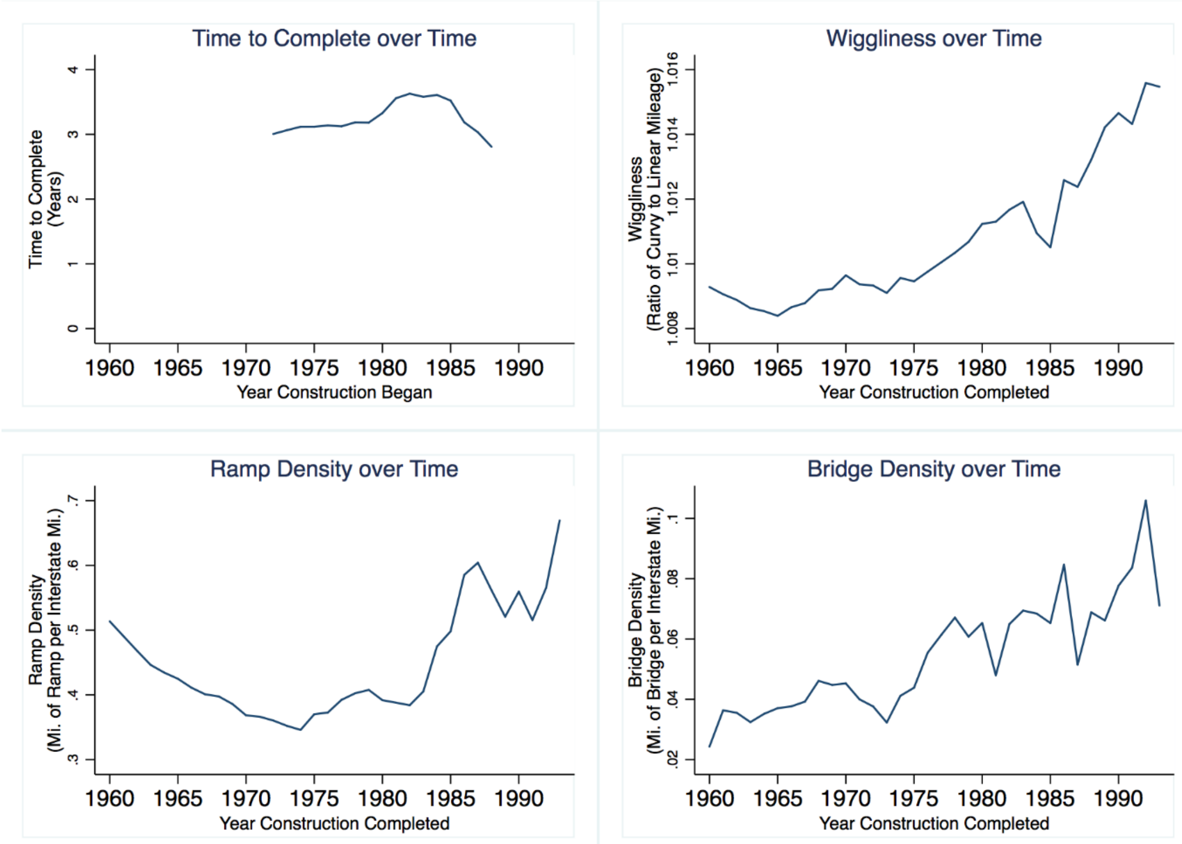
Notes: The pre-1970 and post-1970 values are given as the weighted average of residuals (respectively pre-1970 and post-1970) from column (3) of Table 2 summed with the weighted average of the period effects (respectively pre-1970 and post-1970, and also from column (3) of Table 2). The result is scaled so the minimum pre-1970 value is 0.

Figure 4. Spending per Mile and Highway Wage and Materials Prices



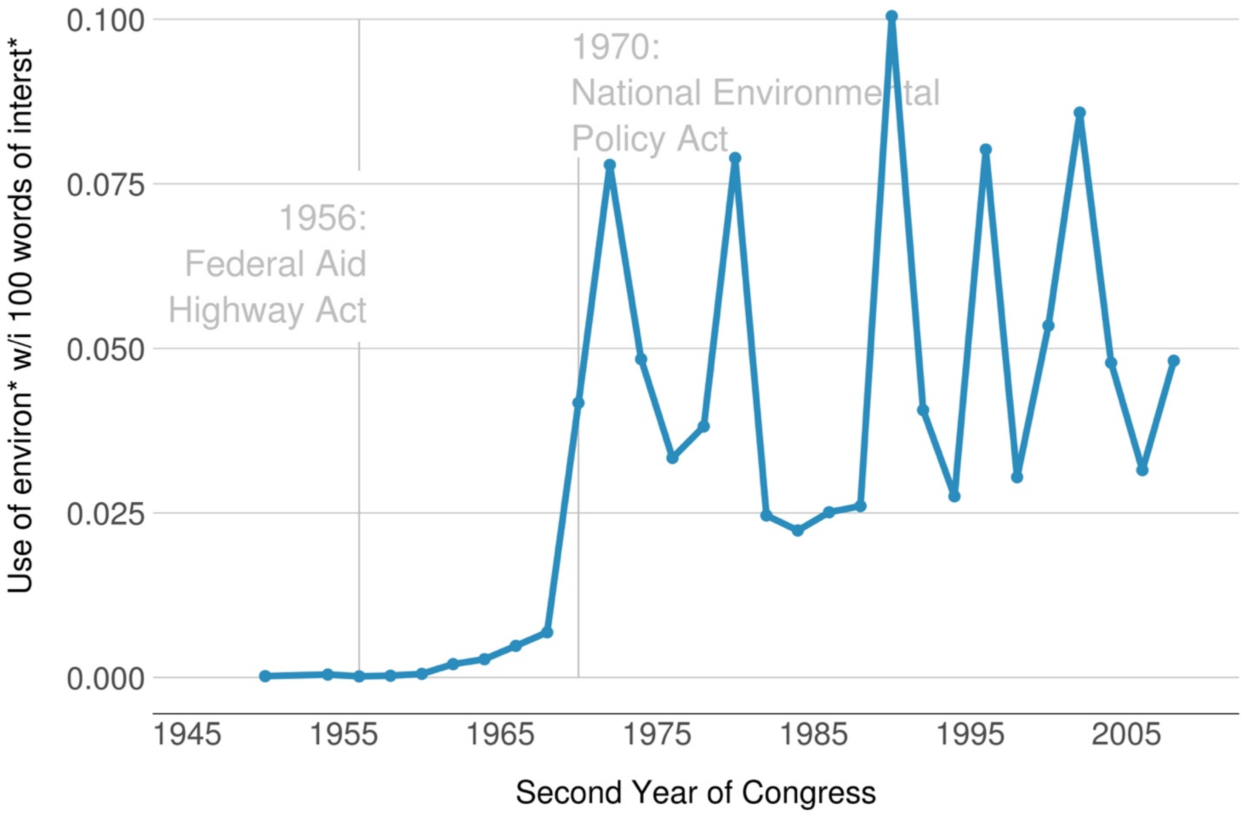
Notes: This figure shows Interstate spending per mile from our 6-year periods, along with the construction hourly wage (in blue; BLS), construction compensation per full time employee (dashed blue; BEA), and materials prices (yellow; BLS). We index all figures to 100 in 1962.

Figure 5. Time Trends in Interstate Attributes



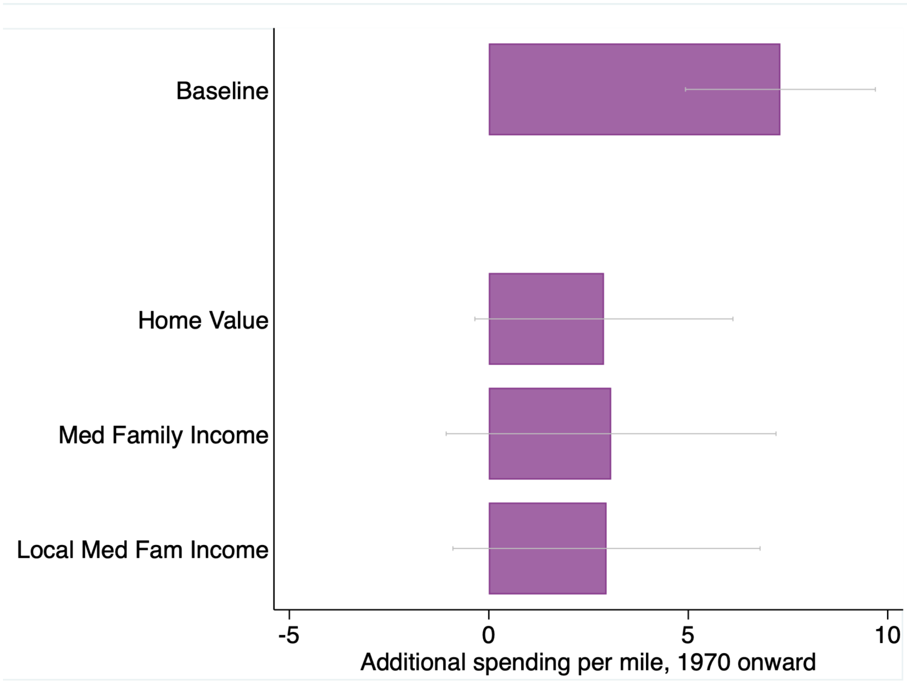
Notes: Completion time defined as the time elapsing between the start and end year of a segment's construction. For this variable, data are excluded before 1966 because of missing data. Wiggliness is the ratio of the 1-mile true length of a segment to the shorter distance connecting the segment's endpoints "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 6. Prevalence of Words Beginning with “Environ*” Near Interstate Increases After 1970



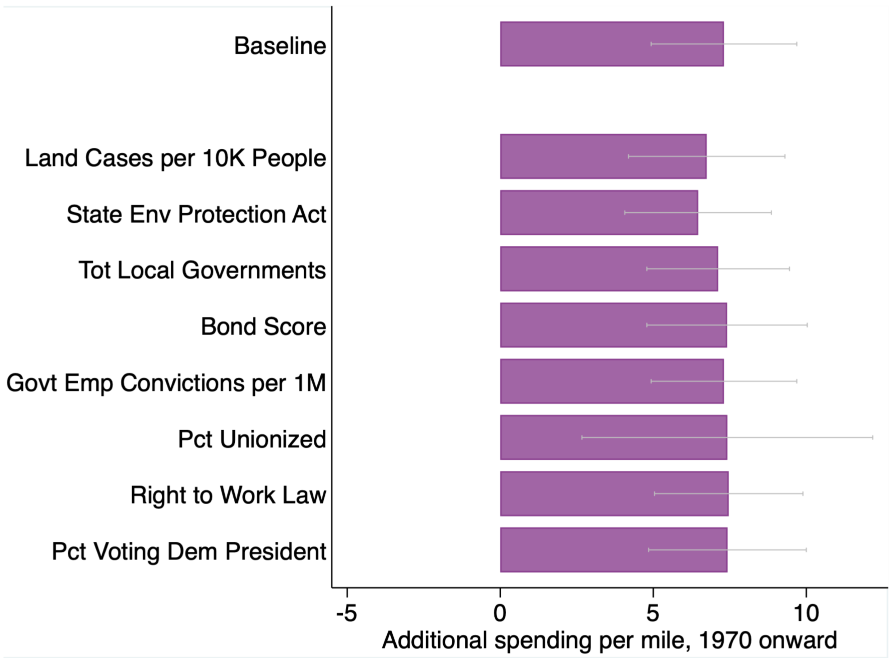
Notes: This figure uses as its sample the 100 words preceding and after each instance of “interst” appearing in the Congressional Record. Here we report the number of times the stem "environ" appears in each session, divided by the number of times “interst” appears in that same session. Peaks after 1980 coincide with discussion of the federal transportation bill.

Figure 7. Change in Spending per Mile, Conditional on Income and Housing Price



Notes: Bars represent summary measure T (equation 2), total change in spending per mile after 1970, with and without additional covariates. Grey lines are 95% confidence intervals. Spending per mile is in millions of 2016 USD. Includes state fixed effects and standardized right-hand side variables.

Figure 8. Change in Spending per Mile, Conditional on Political and Institutional Features



Notes: Bars represent summary measure T (equation 2), total change in spending per mile after 1970, with and without additional covariates. Grey lines are 95% confidence intervals. Spending per mile is in millions of 2016 USD. Includes state fixed effects and standardized right-hand side variables.

Table 1. Summary Statistics Show Spending Increase

	Period is					
	1958-1963	1964-1969	1970-1975	1976-1981	1982-1987	1988-1993
	(1)	(2)	(3)	(4)	(5)	(6)
Spending Per Mile,	8.50	8.91	11.68	16.18	24.57	34.25
millions of 2016 dollars	(6.53)	(5.41)	(10.17)	(15.14)	(34.40)	(45.06)
New miles built	288.8	427.3	301.4	153.6	79.4	59.0
	(195.8)	(254.8)	(196.9)	(87.7)	(59.1)	(38.9)
State average for segments constructed in this period						
Pop. density, (1000s people/sq mi)	0.61	0.48	0.43	0.45	0.61	0.77
	(0.89)	(0.52)	(0.50)	(0.76)	(0.59)	(0.77)
Share of segments in wetlands, rivers,	0.03	0.03	0.04	0.05	0.05	0.07
or other waters	(0.02)	(0.02)	(0.03)	(0.06)	(0.04)	(0.07)
Slope in degrees	2.67	3.04	2.94	3.30	3.24	4.04
	(1.29)	(1.52)	(1.77)	(1.80)	(1.83)	(3.50)
State median family income	44,316	56,357	61,830	57,269	54,960	57,446
	(7,685)	(9,459)	(8,535)	(6,475)	(6,774)	(8,667)
Observations	48	48	48	47	43	36

Notes: We report averages of state-level aggregate measures, weighted by mileage.

Table 2. Inclusion of Geographic Controls Has Little Impact on Spending per Mile Increase

	(1)	(2)	(3)	(4)
Period Indicators, Years are				
1964-1969	0.41	0.02	1.07	0.75
	(0.72)	(1.13)	(0.85)	(0.92)
1970-1975	3.18***	3.30**	4.25***	4.20***
	(0.97)	(1.51)	(1.07)	(1.32)
1976-1981	7.69***	8.36***	7.76***	8.80***
	(1.64)	(1.96)	(1.54)	(1.76)
1982-1987	16.07***	15.75***	14.94***	15.72***
	(2.87)	(3.11)	(2.82)	(3.11)
1988-1993	25.75***	25.31***	21.83***	23.94***
	(7.54)	(7.80)	(7.50)	(8.29)
Geographic covariates, state average of segments constructed				
Population Density, 1000s people/sq mi			8.78***	5.65**
			(1.63)	(2.47)
Share intersecting wetlands, rivers			21.56**	-2.92
or other water			(10.17)	(33.99)
Slope			1.26***	0.66
			(0.31)	(0.60)
State Fixed Effects		X		X
Summary Measure of Temporal Change: *T*	6.78	7.20	6.66	7.31
	(1.08)	(1.19)	(1.07)	(1.18)
Observations	270	270	270	270
R2	0.14	0.36	0.34	0.40

Notes: The dependent variable is real $2016 spending per mile in 6-year periods by state. Standard errors clustered by state. Regressions are weighted by mileage. Excluded time period is 1958-1963. * p<0.10, ** p<0.05, *** p<0.01

Table 3. Summary Measure of Change Robust to Specification and Sample Changes

	Summary Measure of Change *T*	t value, hypothesis Tests, H_0 is		Observations
		T = 0	T = T_baseline	
	(1)	(2)	(3)	(4)
Panel A. Table 2 Specifications				
Col. 1: no covariates	6.78	6.28		270
Col. 2: state fixed effects	7.20	6.07		270
Col 3: geography	6.66	6.22		270
Col 4: geography + state FE	7.31	6.17		270
All remaining specifications described relative to Panel A, final row				
Panel B. Alternative Geographic Specifications				
+ geographic cov. squared	7.13	5.96	0.30	270
+ geographic cov. squared and cubed	6.98	5.87	0.53	270
+ ecoregions	7.18	6.18	0.31	270
Panel C. Robustness to Sample				
balanced panel	7.66	5.43	0.37	210
drop last period	5.87	5.10	0.88	234
balanced panel, no last period	6.17	4.54	1.05	175

Notes: This table reports the summary measure of temporal change in pre- and post-1970 spending per mile. Column 2 tests the null hypothesis that the measure T in the row is equal to zero. Column 3 tests the null hypothesis that T is equal to the “baseline” T, which is the final row in Panel A. Column 4 reports the number of observations in each specification.

Table 4. Relationship Between Spending Per Mile and Input Prices: Small Impact on Summary Measure of Temporal Cost Change

		Additional Hourly Wage Covariate	
	Baseline	CPS, occupation	CPS, industry
	(1)	(2)	(3)
Period Indicators, Years are			
1964-1969	0.75	1.04	2.23
	(0.92)	(1.03)	(2.38)
1970-1975	4.20***	4.83***	6.93*
	(1.32)	(1.42)	(4.04)
1976-1981	8.80***	8.54***	10.40***
	(1.76)	(1.67)	(3.33)
1982-1987	15.72***	13.88***	16.84***
	(3.11)	(3.03)	(3.67)
1988-1993	23.94***	22.00***	25.09***
	(8.29)	(8.03)	(8.89)
Wage Measure in Column Title		-2.00	-1.64
		(1.40)	(2.38)
Geographic Covariates	X	X	X
State Fixed Effects	X	X	X
Summary Measure of Temporal Change: *T*	7.31	7.11	8.57
t statistic, H_0: T = 0	6.17	6.37	3.63
t statistic, H_0: $T = T_{baseline}$		1.02	0.79
Observations	270	269	269
R^2	0.40	0.40	0.40

Notes: The dependent variable is real $2016 spending per mile in 6-year periods by state. Standard errors clustered by state. Regressions are weighted by mileage. Excluded time period is 1958-1963. * p<0.10, ** p<0.05, *** p<0.01

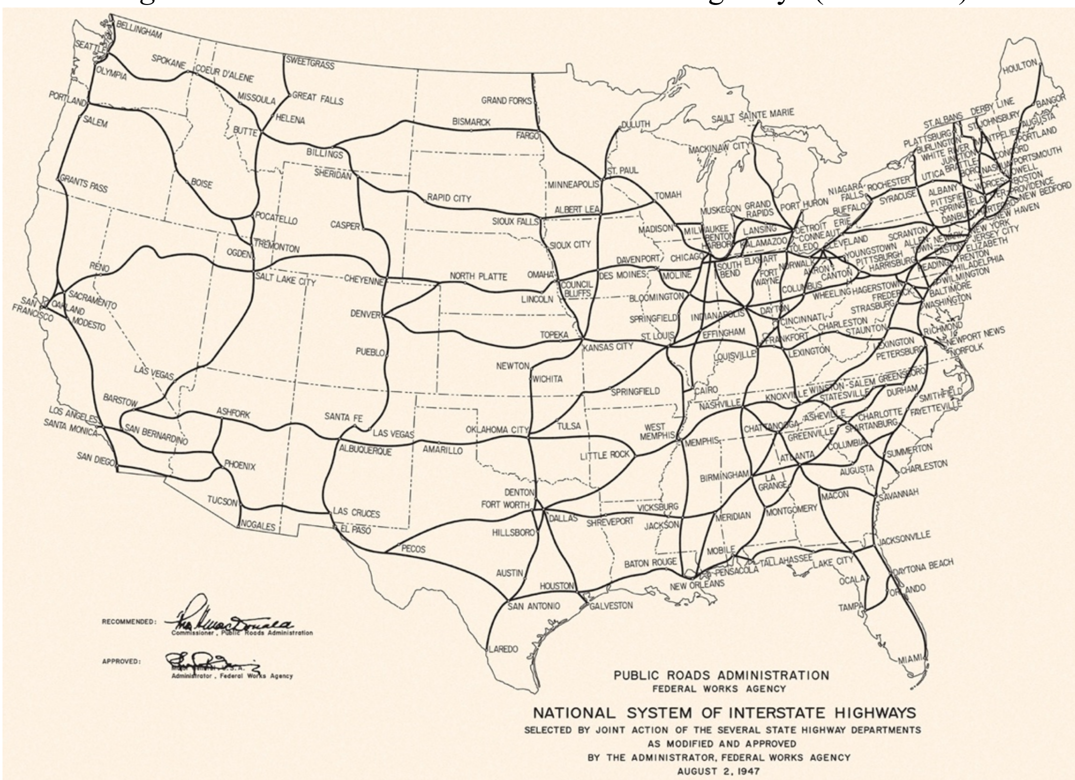
Table 5. Relationship Between Spending Per Mile and Demand Factors: Large Impact on Summary Measure of Temporal Cost Change

	Baseline	Alternative Specifications					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Period Indicators, Years are							
1964-1969	0.75	-5.67*	0.42	-4.04	-2.77*	-6.03**	-0.31
	(0.92)	(3.07)	(1.02)	(2.52)	(1.61)	(2.98)	(1.89)
1970-1975	4.20***	-5.01	3.62**	-2.77	-1.29	-5.89	1.10
	(1.32)	(4.46)	(1.41)	(3.58)	(2.40)	(4.31)	(2.81)
1976-1981	8.80***	1.66	-0.34	-5.01	2.02	-1.17	4.01
	(1.76)	(3.41)	(2.92)	(4.16)	(2.89)	(3.84)	(3.06)
1982-1987	15.72***	10.05***	3.97	0.42	6.71	4.71	8.08*
	(3.11)	(3.52)	(4.86)	(5.27)	(4.96)	(5.05)	(4.81)
1988-1993	23.94***	16.77**	13.24*	8.61	13.18	10.55	13.73*
	(8.29)	(8.17)	(6.71)	(6.40)	(8.32)	(8.28)	(7.70)
Demand Covariates							
State Median Family Income		5.24**		3.64*		3.08	
		(2.50)		(1.96)		(1.95)	
Local Housing Values			6.34***	6.13***			
			(1.73)	(1.71)			
Local Median Family Income					4.68**	3.98**	1.19
					(2.04)	(1.95)	(2.22)
Local Income * 1{year > 1970}							4.52**
							(1.55)
Summary Measure of Temporal Change: *T*	7.31	3.07	2.89	0.08	2.95	1.10	3.51
t statistic, H_0: T = 0	6.17	1.49	1.80	0.04	1.54	0.47	1.86
t statistic, H_0: $T = T_{baseline}$		2.43	3.59	3.69	2.69	2.95	2.27
Observations	270	270	270	270	270	270	270
R^2	0.40	0.40	0.44	0.44	0.41	0.41	0.43

Notes: The dependent variable is real $2016 spending per mile in 6-year periods by state. Standard errors clustered by state. Regressions are weighted by mileage. Excluded time period is 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

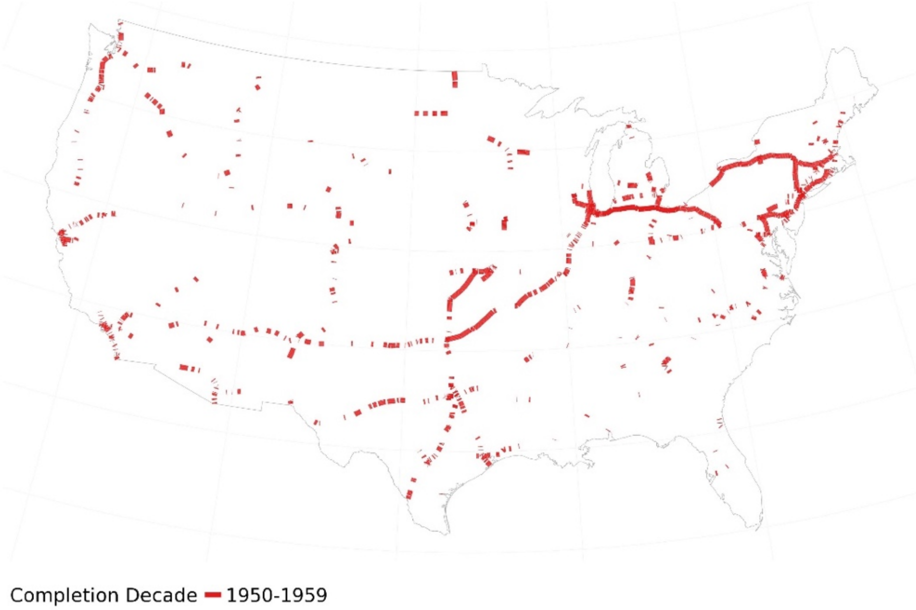


Figure A2ii. Interstates Opening 1960-1969

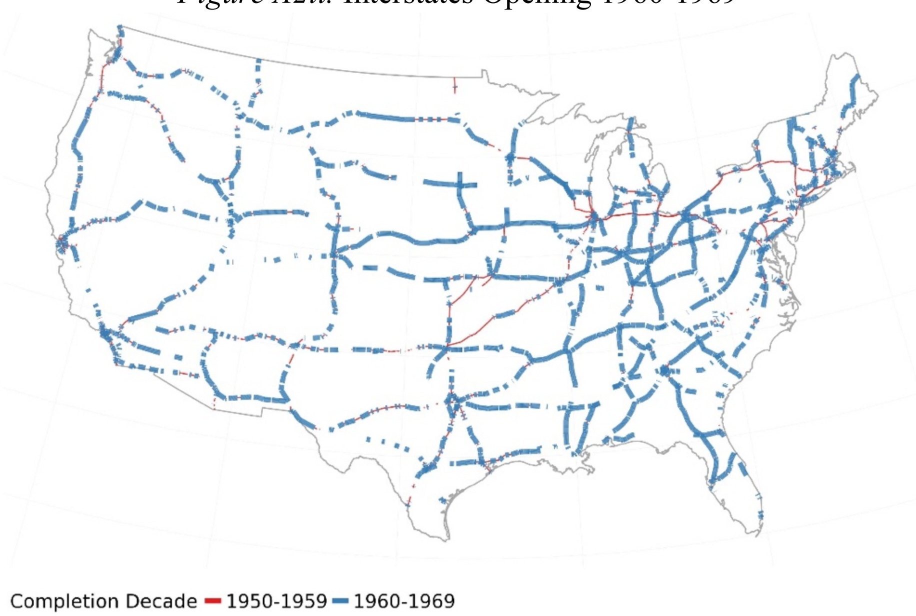


Figure A2iii. Interstates Opening 1970-1979

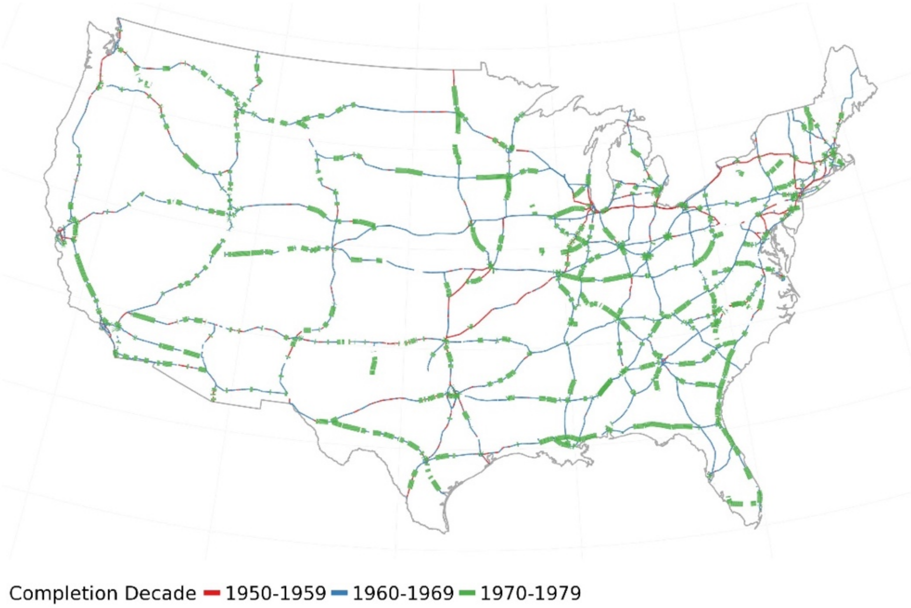


Figure A2iv. Interstates Opening 1980-1989

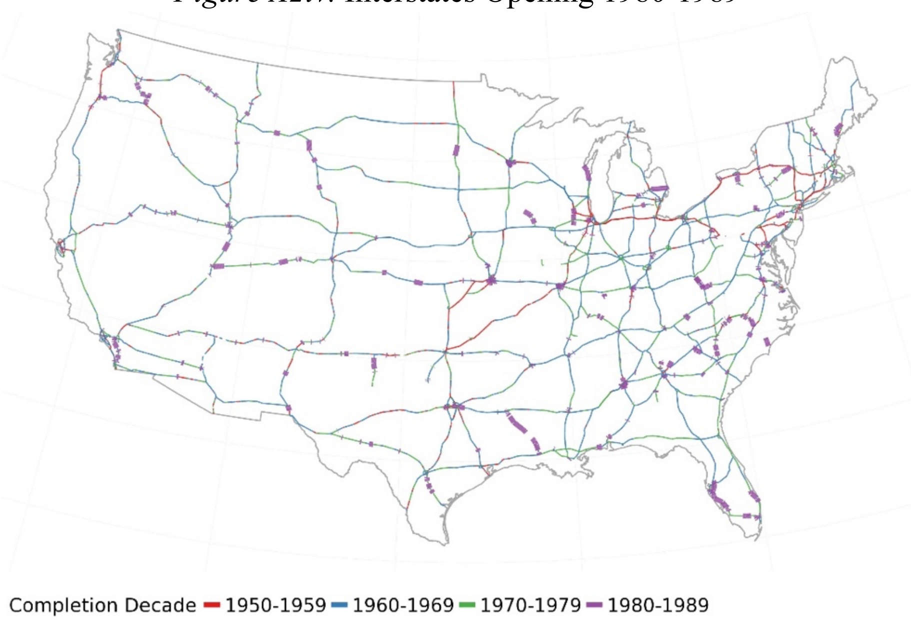


Figure A2v. Interstates Opening 1990-1993

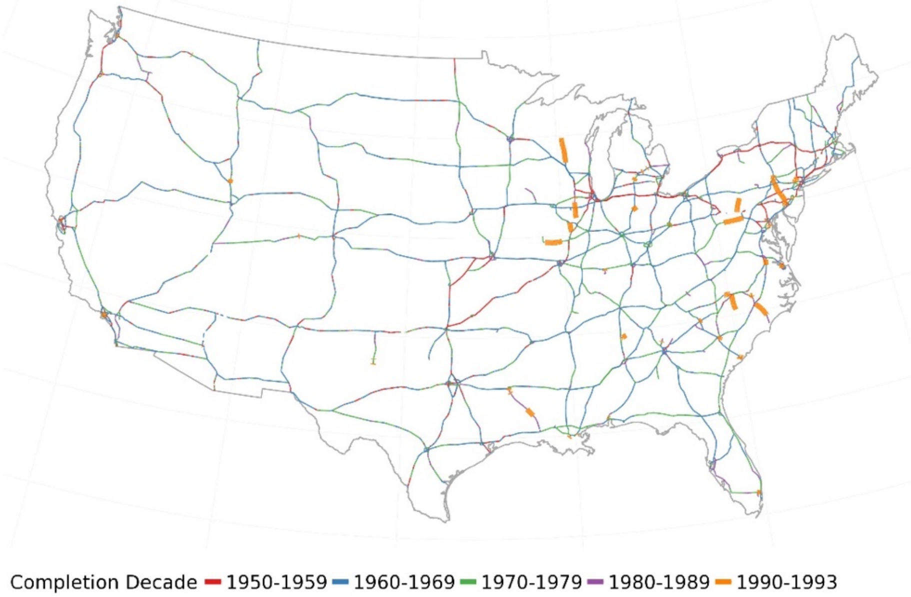


Figure A2vi. Full Interstate System

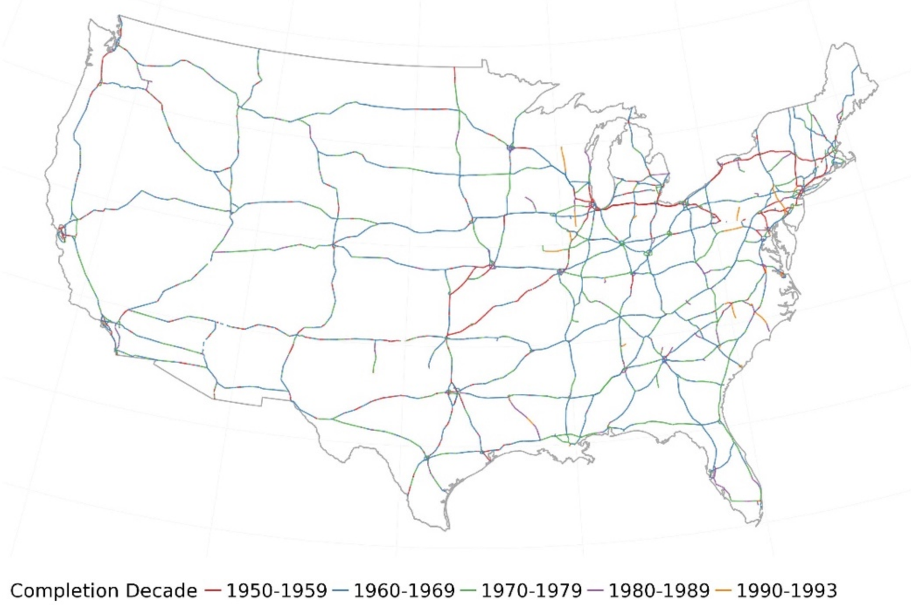


Figure A3. Spending per Mile: Pre-1970 vs. Post-1970 (Not Controlling for Geography)

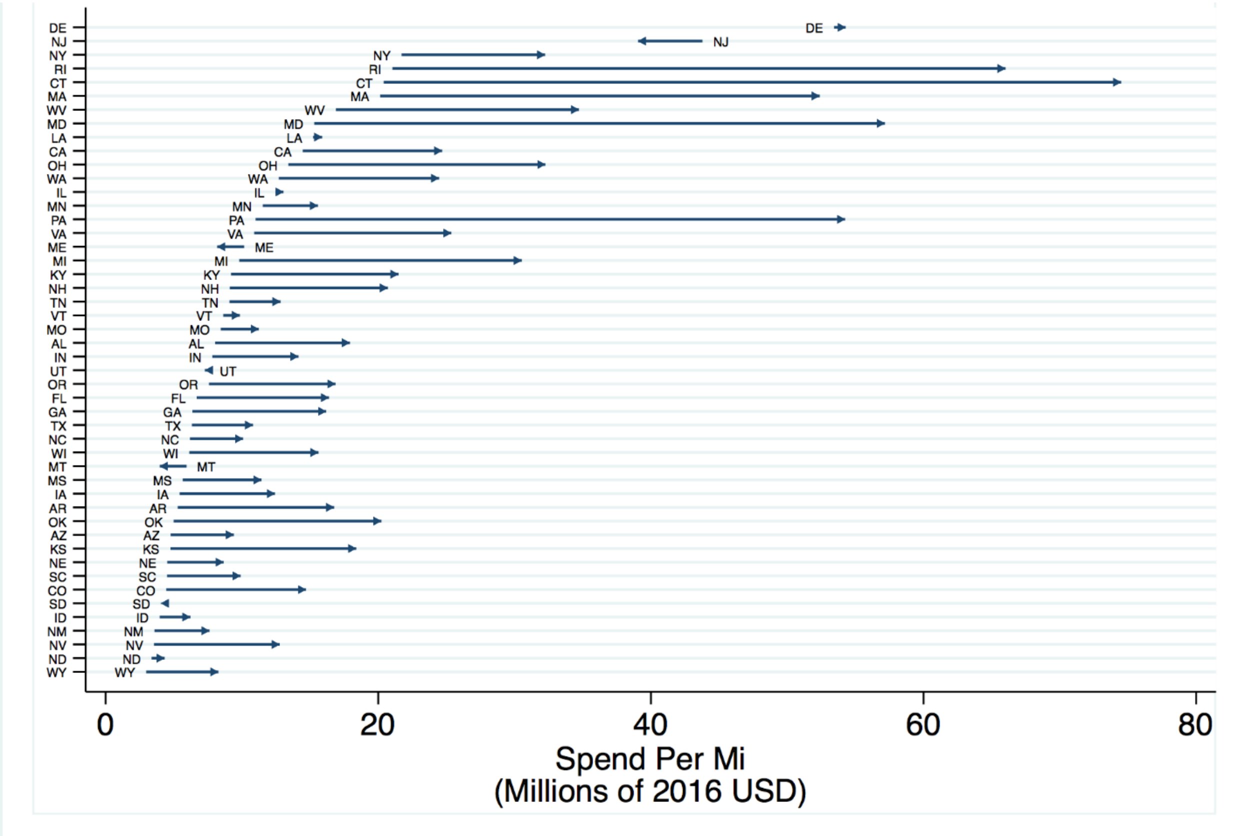
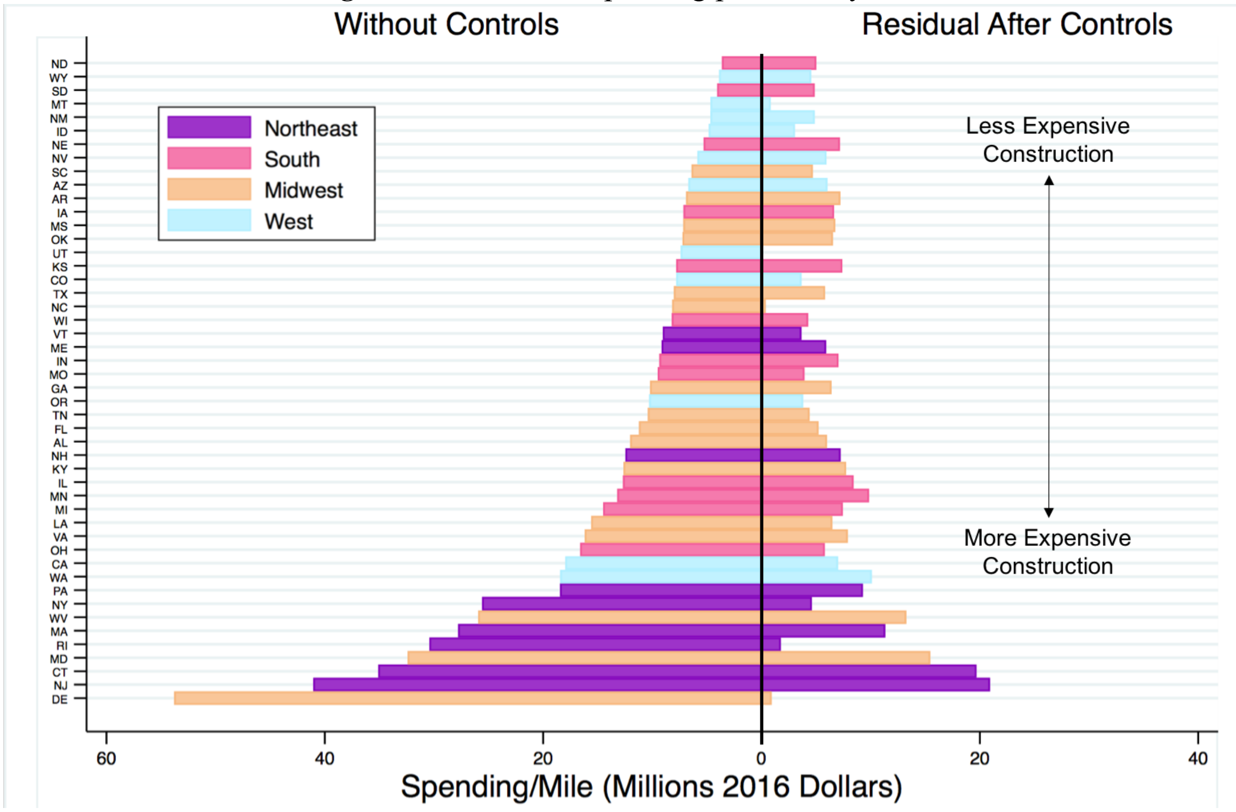


Figure A4. Interstate Spending per Mile by State



Notes: State-level values in the right column given as the miles-weighted average of residual spending per mile (millions 2016 USD) after controlling for geography (from column (3) of Table 2). Residuals are scaled so the minimum average is 0.

Figure A5i. Interstate Spending per Mile by State (Not Controlling for Geography)

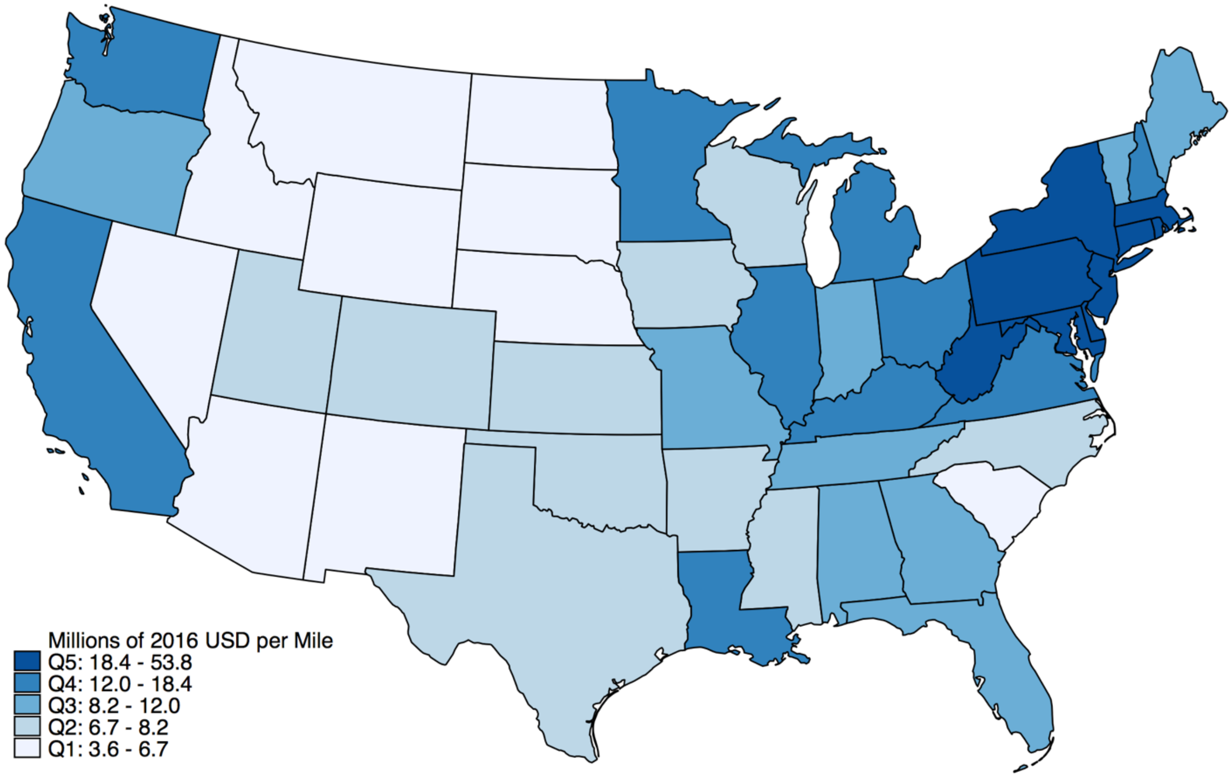
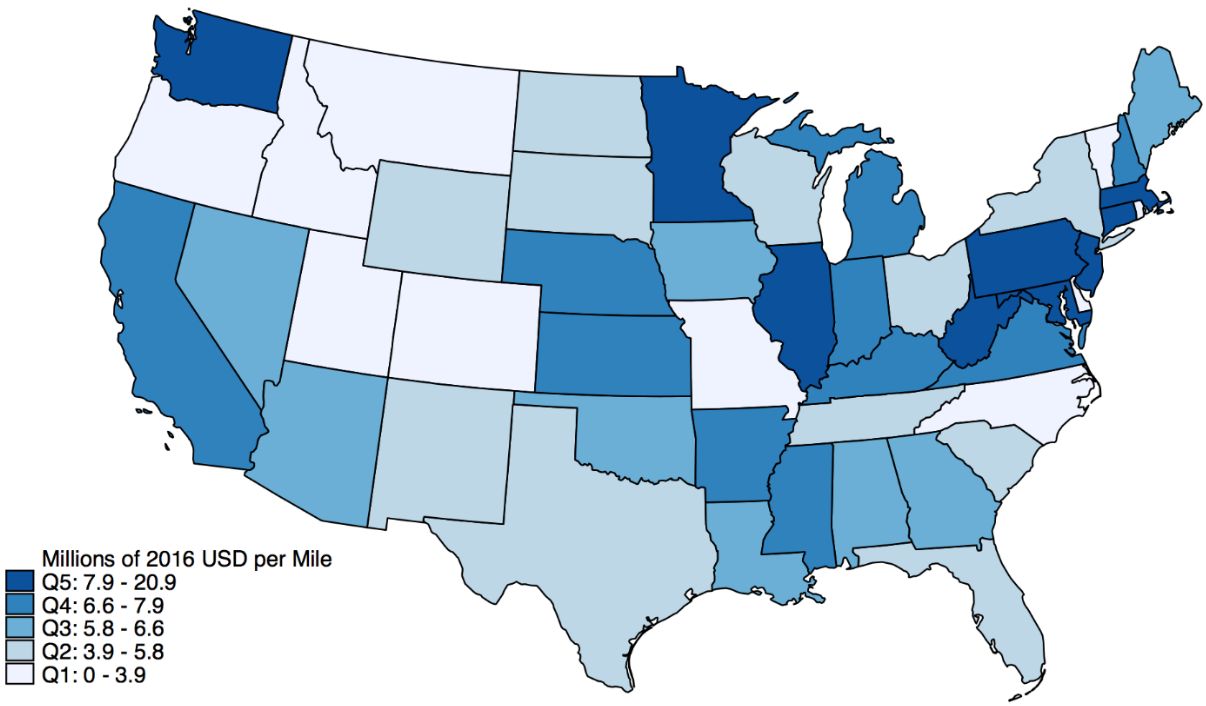
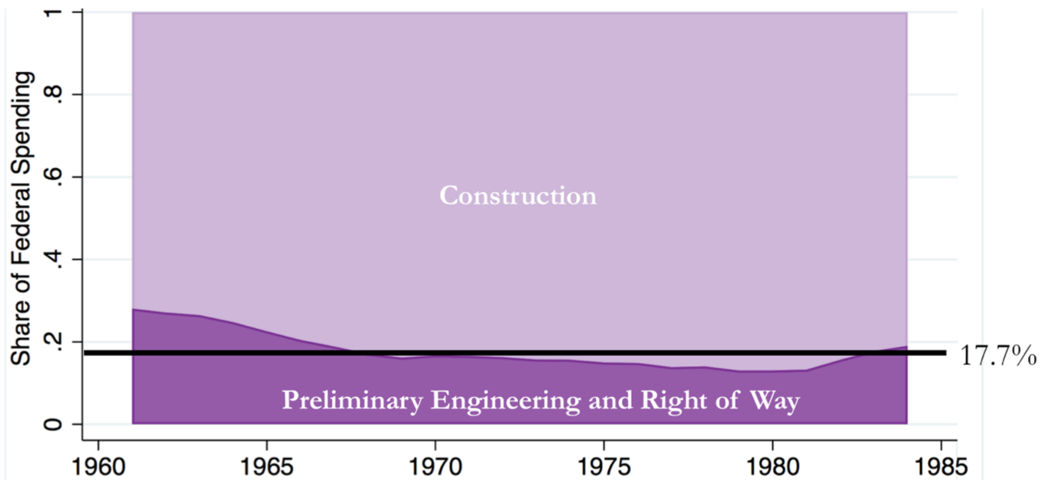


Figure A5ii. Interstate Spending per Mile by State, After Controlling for Geography



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 A6. 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 A7: Time Trends in Interstate Attributes Controlling for Geography

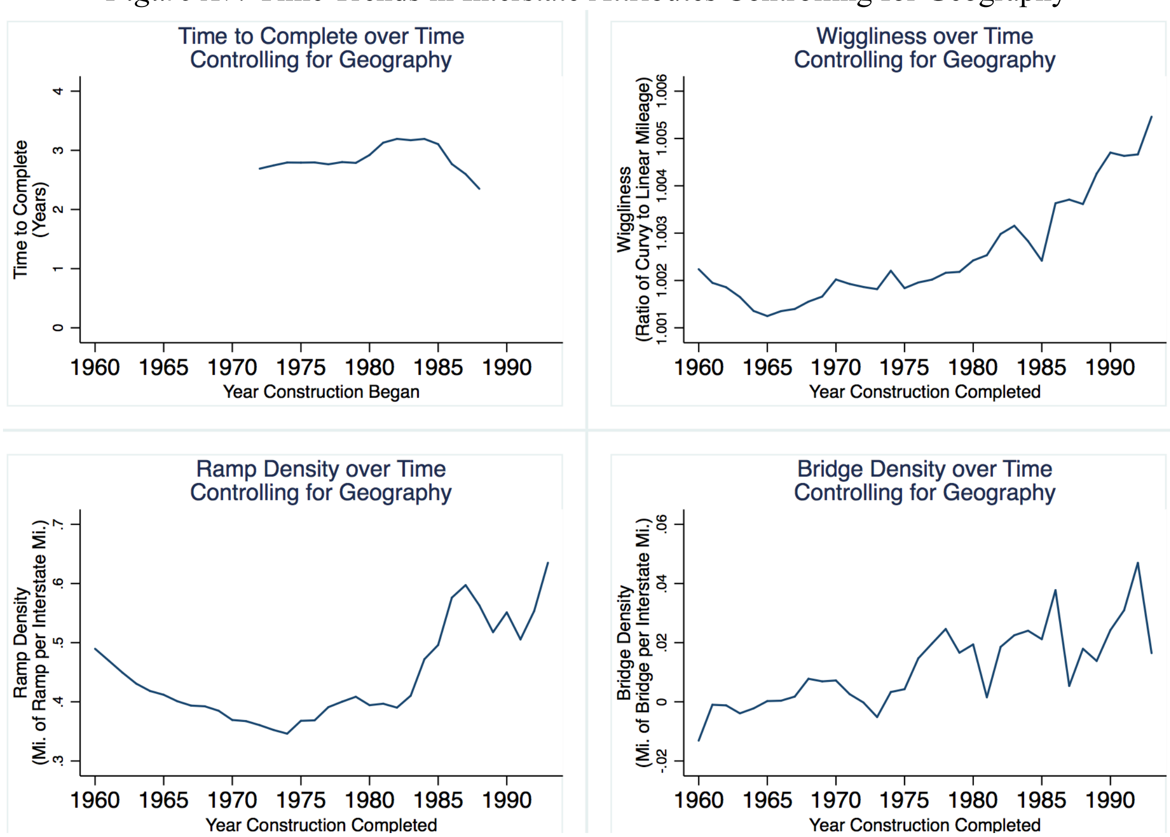


Figure A8. Pedestrian Plazas Across I-696 in Oak Park

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

Table A1. Mileage Openings Most Strongly Related to Spending in Two Years Prior

	(1)
Year *t* Expenditure	41.096***
	(15.242)
Year *t* -1 Expenditure	33.474***
	(10.981)
Year *t* -2 Expenditure	14.877**
	(5.802)
Year *t* -3 Expenditure	3.201
	(9.450)
Year *t* -4 Expenditure	5.282
	(9.355)
Year *t* -5 Expenditure	-8.180
	(6.290)
Year *t* -6 Expenditure	18.128
	(10.809)
Year *t* -7 Expenditure	-15.246
	(10.948)
Year *t* -8 Expenditure	-8.848
	(11.143)
Year *t* -9 Expenditure	7.300
	(5.230)
Year *t* -10 Expenditure	-9.328
	(6.812)
Year *t* +1 Expenditure	-6.694
	(13.358)
Year *t* +2 Expenditure	-11.992
	(12.201)
Year *t* +3 Expenditure	8.936
	(13.148)
Year *t* +4 Expenditure	0.392
	(12.147)
Year *t* +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	1.01	-1.63	0.11	0.97	1.67	0.96	0.88	0.97	1.53
	(0.92)	(2.92)	(1.18)	(0.87)	(1.18)	(0.91)	(0.90)	(0.94)	(1.18)
Yr='71-'75	4.71***	6.89*	3.99**	4.70***	4.75***	4.72***	4.63***	4.82***	4.51***
	(1.44)	(3.89)	(1.59)	(1.43)	(1.71)	(1.39)	(1.37)	(1.44)	(1.62)
Yr='76-'81	8.69***	20.24**	8.19***	8.71***	9.30***	8.90***	8.76***	8.59***	9.25***
	(1.74)	(8.41)	(2.06)	(1.63)	(1.91)	(1.79)	(1.81)	(1.77)	(1.86)
Yr='82-'87	15.61***	42.74*	15.57***	15.78***	14.90***	15.18***	15.13***	15.71***	14.60***
	(3.11)	(23.52)	(3.16)	(3.10)	(3.25)	(3.13)	(3.16)	(3.23)	(3.25)
Yr='88-'93	23.65***	55.15***	24.69***	23.68***	23.37***	23.02***	22.96***	24.25***	22.86***
	(8.24)	(16.05)	(8.50)	(7.98)	(7.97)	(8.26)	(8.38)	(8.44)	(8.10)
Pop Density	6.01**	8.40		6.49***	6.20***	11.69**	12.98	5.95**	8.29
	(2.51)	(5.31)		(2.14)	(2.00)	(4.51)	(13.94)	(2.54)	(14.29)
Pop Density (2nd order)						-1.63	-6.66		-2.92
						(2.22)	(21.50)		(21.82)
Pop Density (3rd order)						0.06	3.70		2.69
						(0.23)	(11.41)		(11.49)
Pop Density (4th order)							-0.82		-0.71
							(2.23)		(2.23)
Pop Density (5th order)							0.06		0.05
							(0.14)		(0.14)
Static Pop Density			0.01						
			(0.02)						
Share Intersecting Wetlands, Rivers, & Other Waters	3.75	-80.18	0.22		-15.21	5.74	5.79	-83.45	-10.84
	(32.93)	(127.07)	(35.84)		(33.23)	(31.50)	(32.37)	(264.68)	(136.02)
Share Wetlands (2nd order)								1575.04	-423.65
								(3574.21)	(1267.69)
Share Wetlands (3rd order)								-11347.88	1760.36
								(17174.54)	(2907.37)
Share Wetlands (4th order)								24536.61	
								(26597.69)	
Slope (Degrees)	0.78	-1.73	0.37	0.69	0.50	0.70	0.63	0.81	0.25
	(0.57)	(2.12)	(0.71)	(0.60)	(0.65)	(0.60)	(0.64)	(0.65)	(0.77)
County Wetland Density				-6.48					
				(7.27)					
Max Summer Temp (deg F)					1.55**				1.50**
					(0.63)				(0.61)
Min Winter Temp (deg F)					0.08				0.25
					(0.52)				(0.55)
Annual Rainfall (Inches)					0.33				0.15
					(0.35)				(0.32)
Observations	269	269	269	269	269	269	269	269	269
R^2	0.411	0.307	0.372	0.414	0.448	0.418	0.419	0.414	0.458
Adjusted R^2	0.259	0.129	0.210	0.262	0.264	0.260	0.255	0.252	0.255

Notes: Mean of the outcome variable is 11.51 (2016 USD). Standard errors clustered by state. Regressions are weighted by mileage and include state fixed effects. Columns 5 and 9 also include eco-region fixed effects. Excluded period begins in 1958 and ends at the first period shown. * p<0.10, ** p<0.05, *** p<0.01

Table A3: Effect of Combinations of Highway Characteristics on Spending per Mile

	(1) Structure Density	(2) Segment Wiggliness	(3) Struct & Wiggly	(4) Struct, Wiggly & Lane	(5) Struct, Wiggly, Lane & Comp Time
Yr='64-'69	0.63	0.39	0.32	0.65	0.59
	(1.01)	(0.96)	(1.07)	(1.05)	(1.05)
Yr='70-'75	4.65***	3.59**	4.04**	4.49***	5.44***
	(1.44)	(1.52)	(1.66)	(1.56)	(1.98)
Yr='76-'81	8.09***	7.51***	7.00***	7.94***	9.10***
	(1.60)	(1.81)	(1.71)	(1.89)	(2.61)
Yr='82-'87	12.55***	13.00***	10.47***	11.65***	12.51***
	(3.13)	(3.21)	(3.31)	(3.72)	(4.14)
Yr='88-'93	21.65***	19.24**	17.65**	19.92**	22.01**
	(7.94)	(8.37)	(8.15)	(9.19)	(10.69)
Structure Density	6.13***		5.35***	5.13***	5.08***
	(1.66)		(1.74)	(1.75)	(1.74)
Segment Wiggliness		6.17*	5.62	5.83	5.82
		(3.57)	(3.68)	(3.64)	(3.67)
Number of Lanes				2.93	2.88
				(1.82)	(1.84)
Years to Complete					-0.90
					(1.15)
R^2	0.433	0.446	0.473	0.483	0.485
Summary Measure of Temporal Change, T	6.97	6.28	6.08	6.64	7.73
(se)	1.13	1.21	1.20	1.35	2.10
Summary Measure, T vs. Baseline	0.34	1.03	1.23	0.67	-0.42
(se)	0.41	0.69	1.67	1.55	1.87

Notes: Mean of the outcome variable is 11.51 (2016 USD). Standard errors clustered by state. Regressions are weighted by mileage and include state fixed effects. Excluded time period category is for 1958-1963 and periods are 6 years long. * p<0.10, ** p<0.05, *** p<0.01

Appendix A - Data Summary and Variable Construction

I. Variable Construction

We study the relationship of highway spending with a variety of variables, which we get from many sources. This appendix reviews the sources and construction for each variable. Where available, we use data at relatively fine geographical and temporal granularities (tract or county, and year), which allows us the fullest use of our knowledge of where and when Interstate mileage opened. For policy topics where we observe only state-level values or values at a single point in time, we are not able to take advantage of this same knowledge.

Initially, we make four brief notes on the construction of our variables. First, many make use of supporting datasets, from the Census in particular. These Census datasets are documented below:

State and County level

- 1940: ICPSR 02896, Historical, Demographic, Economic and Social Data: The United States, 1790-2002, Dataset 38: 1950 Census I (County and State)
- 1950
  - ICPSR 02896, Historical, Demographic, Economic and Social Data: The United States, 1790-2002, Dataset 38: 1950 Census I (County and State)
  - Census of Population, 1950 Volume II, Part I, Table 32.
- 1960: ICPSR 02896, Historical, Demographic, Economic and Social Data: The United States, 1790-2002, Dataset 38: 1960 Census I (County and State)
- 1970: ICPSR 8107, Census of Population and Housing, 1970: Summary Statistic File 4C -- Population [Fourth Count]
- 1980: ICPSR 8071, Census of Population and Housing, 1980: Summary Tape File 3A
- 1990: ICPSR 9782, Census of Population and Housing, 1990: Summary Tape File 3A
- 2000: ICPSR 13342, Census of Population and Housing, 2000: Summary File 3
- 2010: U.S. Census Bureau, 2010 Decennial Census Summary File 1, Downloaded from http://www2.census.gov/census_2010/04-Summary_File_1/
- 2010 (2008-2012): U.S. Census Bureau, American Community Survey, 5-Year Summary File, downloaded from http://www2.census.gov/acs2012_5yr/summaryfile/2008-2012_ACSSF_All_In_2_Giant_Files\%28Experienced-Users-Only\%29/
- 1952-1992 (every 5 years): Census of Governments–Vol. 1, no. 1. Government Organization. Downloaded from the Census Bureau's "Census Bureau Reports About Governments": https://www.census.gov/govs/pubs/year.html

Tract level

- Shapefiles
  - 1940, 1950, 1960, 1970, 1980 from NHGIS (Minnesota Population Center. National Historical Geographic Information System: Version 2.0. Minneapolis, MN: University of Minnesota 2011)

- o 1990 through 2010 from block group shapefiles provided by the US Census Bureau on their website.
- Historical Data
  - o 1940, 1950, 1960 form NHGIS (datasets 76, 82, and 92)
  - o 1970, 1980, 1990 and 2000 from the Interuniversity Consortium Political and Social Research (1970: Summary Tape File 4a #6712, 1980: Summary Tape File 3a #8071, 1990: Summary Tape File 3a #9782)
  - o 2010 (officially the 5-year estimates for 2008 to 2012 from the American Community Survey) directly downloaded from the Census website.

Second, our Interstate data from Baum-Snow (2007) partitions the Interstates into sections of varying lengths for which we observe opening dates. Based on these sections, we divide the Interstates into roughly one-mile long segments. These segments underlie many of our measures (e.g., the fraction of miles in a given state-year that pass through counties with characteristic X). We generally measure the segments by their true (according to a high-fidelity map from Baum-Snow (2007)) length, but also compute the end-to-end "as the crow flies" length of the segment to explore how segment "wiggliness" correlates with per mile construction spending.

Third, the descriptions below make reference to "periods," for example as in "state-period level data." Used as such, "period" is a placeholder for a unit of temporal aggregation. In most of our analysis (Tables 1 - 5, Figures 2 and 4) this unit is 6 years. Elsewhere, it is one year (Figures 5 and 6). The descriptions are written to accurately apply to both units of analysis.

Fourth, unless otherwise specified, we backfill the values of our state-year aggregated time series measures that aren't available until after 1956 (when our data on spending and mileage begin) or that are missing for select state-years with the value in the nearest future year. We likewise fill forward using the nearest past value for any state-years from 1956 to 1993 for which a given variable is still missing after backfilling.

a. Population Density
We construct a state-year level measure of the urban-intensity of miles built using population density data from the Census. For most segments, we simply take the population of the segment's tract from the nearest decennial Census and divide by the tract area (in square miles). For segments in areas not yet tracted at the time of their opening, we instead take the county population and area from the nearest decennial Census. Our state-period level measure is then the segment length-weighted average[55] of this measure across all segments opened in the given state and period.

b. Wetland Geography
To assess whether wetlands may have impacted per mile construction spending, we overlap a wetlands map from the US Fish and Wildlife Service with our segment data derived from Baum-Snow (2007) (US Fish and Wildlife Service 2018). This wetlands map is ecologically broad, covering documented waters that fall under the Cowardin classification system, which includes

[55] Here and in the descriptions that follow, the length we use for weighting is the length of the segment "as the crow flies," though this length is very narrowly distributed around 1 so the weighted average approximates a standard arithmetic average.

marine (roughly, oceanic), estuarine, riverine (roughly, flowing fresh water), lacustrine (roughly, lake waters), and palustrine (roughly, non-river and non-lake fresh water) categories. Our segment-level measure is then the share of a segment's length passing through any part of this wetland map. At the state-period level, our measure is the segment length-weighted average share of opened mileage constructed through wetland.

c. Topography
As a control for the impact of topography on per mile construction spending, we create a measure of the slope of the terrain in the area each Interstate highway segment is built. The granularity of our topographical data is 1 arcsecond (roughly a 30 meter by 30 meter grid), and the data was collected by satellite in 2004. Our measure consists of averaging the slope values of each cell of data within 50 meters of each segment. The slope for a given cell is defined as the average difference between the cell's elevation and that of each of its eight neighbors. The state-period level measure is then the segment length-weighted average of these segment-level average slopes.

d. Home Values
To measure median home values, we use data from the decennial U.S. Census, digitized in a number of sources (Haines et al 2010; Minnesota Population Center 2001; Sylla et al 1993; United States 2006a; United States 2006b; United States 2008a; United States 2008b; United States 1988; United States 2012). Collectively, these sources provide tract data on median home values for 1980 and 1990, and county data on median home values for all the decadal years from 1950 to 1990. With each segment, we associate the more granular measure of median home value available—tract or county (generally county pre-1980, generally tract in 1980 and 1990), inflate to 2016 dollars, and scale so the result is in thousands of USD. Our state-period level measure is then the segment length-weighted average home value among those recorded for segments that opened in the given state-period.

e. Median Family Income
To examine the relationship between rising incomes and Interstate spending per mile, we make use of the decennial Census' state-level measure of median family income, linearly interpolated between the decades during which the Census was administered. This measure is adjusted for inflation and scaled to tens of thousands of 2016 USD.

f. Land Use Litigation
Our study of local land use regulatory regimes is based on a historical tabulation of land uses cases from Ganong and Shoag (2017). Available for each contiguous US state, and each year from roughly 1940 to 2010, this tabulation represents the number of cases (per million people) in which the phrase "land use" appears in a state supreme or appellate court case (Ganong and Shoag 2017). Our state level measure for a given year is then simply this count of cases per million in the year, rescaled to the number of cases per ten thousand.

g. Land Use Restrictiveness
We employ a second measure of local land use regulatory regimes: the 2005 Wharton Residential Land Use Regulatory Index (WRLURI). This measure is an index (mean 0, standard deviation 1) created to compare localities' regulatory environments, specifically in 2005

(Gyourko et al, 2008). It is based on municipal survey responses, statewide regulatory conditions, and environmental/open space ballot initiatives, with higher values indicating greater restrictiveness (Gyourko et al, 2008).

Since the index is provided at the level of the municipality, we aggregate the index to the county level with a simple average across municipalities in the county for which the index is available. All remaining counties (including those for which the index could not be computed because they did not contain municipalities with an available index value) are assigned the state's average index value. Each segment of Interstate then takes the index value of the county through which it's built, and our state-level measure for a given year is then the segment length-weighted average index value among segments opened in that state and year.

h. State Environmental Protection Acts

To measure the effect of environmental protection legislation on per mile Interstate spending, we use an indicator equal to one in a given state-year if a restrictive protection act had been passed. We consider the protection acts passed in CA, MA, MN, NY, and WA to have been restrictive based on a) the degree to which parties not injured by a covered "project" can challenge the project in court, b) the significance threshold for triggering environmental review, c) whether the actions of private entities subject to governmental permitting, licensing, or other regulation require environmental review, and d) the scope of procedural opportunities for citizen involvement. In any analysis with units of time greater than one year, we take the share of years with the act in place to be the analogous measure.

i. Government Fragmentation

We construct a measure of government fragmentation using Willamette University's Government Finance Database, a compilation of the historical Censuses and Annual Surveys of Government (Pierson et al. 2015). The Government Finance Database has data beginning in 1967[56] and contains the Census of Governments, which surveys the universe of governments in the U.S. every five years (United States 2018). We linearly interpolate between census years to yield a dataset of the count of local governments (including special governments and school districts) in each county and year. Our segment-level measure of fragmentation is then the (possibly interpolated) number of governments existing in the segment's county in the year of its opening. At the state-period level, our measure is the segment length-weighted average number of governments per county across all segments opened in the state and period.

j. Government Fragmentation (alternate)

Because there is some evidence of severe missing data in the Willamette Government Finance Database in 1967, and as a robustness check against the effect of the missing data before 1967, we create a hybrid state-level measure consisting of counts of governments by state from the Census (Census Bureau Reports About Governments 2019) for 1952, 1957, 1962, and 1967, and from the Willamette database for the remaining census years. As before, we linearly interpolate this measure between years to arrive at an annual measure of the number of governments by state from 1952-1997.

k. Construction Industry Concentration

[56] The Census of Governments has been carried out since 1957, but we do not include years before 1967 because they were not included in the dataset and inclusion would require significant digitization.

As a measure of market concentration in the construction industry, we digitize state-level establishment counts from the "highway and street construction" category of the Construction Census (a component of the Economic Census, hosted by Hathi Trust as digitized by and archived at the University of Michigan in earlier years, and hosted by the Census in later years). The census series runs every 5 years from 1967 and we digitize it through 1992, linearly interpolating between census years. We divide this measure by the state population to yield a concentration-like measure.

l. Construction Industry Earnings before Interest, Taxes, Depreciation, and Amortization (EBITDA)

As a measure of construction industry markups, we digitize several state-level financial variables from the "highway and street construction" category of the Construction Census (a component of the Economic Census), which is conducted every five years, to approximate earnings before interest, taxes, depreciation, and amortization (EBITDA). The Census series begins in 1967 and we digitize it through 1992, applying the following formula, adjusting to 2016 Dollars, and linearly interpolating between census years:

> Total Receipts - (Payroll + materials + components + supplies + subcontractor payments + machinery + equipment + building rent + non land capital expenditures)

Note that the Census' definition of receipts changed between the 1982 and 1987 Census to exclude receipts from work done for the establishment itself and to count receipts only for work done in the relevant year (rather than to count, as was previously the case, receipts for work billed in the relevant year).

m. Unionization Rates

To correlate per mile spending on Interstate construction with unionization rates, we make use of data maintained by Barry Hirsch at Georgia State University and David Macpherson at Trinity University. Their data provides rates of union membership by state, across all sectors, in each year from 1964 onward, as well as rates of union coverage in the private construction industry in each year from 1983 onward. Because the latter measure covers relatively few years, we average it across years by state to obtain a static, state-level measure of unionization rates in the (private) construction industry.

n. State Right to Work Laws

To measure the effect of state right to work laws on per mile Interstate spending, we use an indicator equal to one in a given state-year if the state had a right to work law (whether by statute or constitutional provision) in effect during any part of that year (National Right to Work Committee 2018). In any analysis with units of time greater than one year, we take the share of years with a right to work law in place to be the analogous measure.

o. State Prevailing Wage Laws

To measure the effect of state prevailing wage laws on per mile Interstate spending, we use an indicator equal to one in a given state-year if the state had a prevailing wage law in effect during any part of that year (Philips 1995, p. 4). In any analysis with units of time greater than one year, we take the share of years with a prevailing wage law in place to be the analogous measure.

p. Democratic Vote Share
To measure a state's political leanings in a given year, we use the Presidential vote share in the nearest election. We take the state's vote share for the Democratic candidate to represent its political leaning for the years in our study period, 1956 to 1993 (Federal Election Commission 2017; Leip; Willamette). For analysis with time periods longer than one year, the measure is a simple average of the yearly Democratic vote share across years within the period.

q. Bond Ratings
To measure a state's level of fiscal responsibility, we use data on the state's general obligation debt ratings (or issuer credit rating where the general obligation debt rating is not available) from S&P Global Market (S&P Global Market Intelligence 2016). This dataset provides ratings for each state over time, since the time that S&P first issued each state's rating. (The date of initial rating varied from 1956 for Kansas and Colorado to 2014 for Idaho).

To convert each rating to a numerical score, we assign AAA to a score of 1 then to each of the three classes AA+ to AA-, A+ to A-, and BBB+ to BBB- a score equal to the percent change from the interest rate on a 10-year municipal bond graded in the middle of the class (e.g., AA for the AA+ to AA- class) to the interest rate on a 10-year municipal AAA bond (Violette 2018). Our state-year level measure of a state's fiscal responsibility in a given year is thus the converted bond rating in that year; in analysis with periods of time longer than one year, the measure is a simple average of the yearly bond score across years within the period.

r. State Government Corruption
We also use a corruption index developed in Boylan and Long (2003). Their index is a normalized average of the responses of surveyed State House reporters in each state (excepting NH, NJ, and MA, whose corruption measure we take to be the miles-weighted average across the other states) to 6 questions about fraudulence, bribery, overall corruption, and group-specific (e.g., legislatorial) corruption within state government (Boylan and Long 2003). Higher values of the index indicate greater levels of perceived corruption among respondents. The survey was carried out from March 1998 to March 1999, so the data is only available for one point in time, though we take the index to reflect states' levels of corruption across our study period (Boylan and Long 2003).

s. State Government Corruption (Alternative)
As a secondary measure of state government corruption, we use annual per capita counts of Department of Justice convictions of state employees by state, available from 1976 to 2015. Notwithstanding the criticisms of this measure offered in Boylan and Long (2003), Raghav et al (2009), and Alt and Lassen (2012), it is a commonly used measure of state government corruption. Because the count doesn't begin until 1976, we average the measure across all available years by state to yield a single, static measure of corruption by state.

t. Interstate Structures
To examine the presence of Interstate highway structures, we used a measure based on lengths of nearby Interstate bridges and ramps.[57] Data on these highway structures, themselves represented as segments, come from the 2016 Highway Performance Monitoring System (FHWA 2016a),

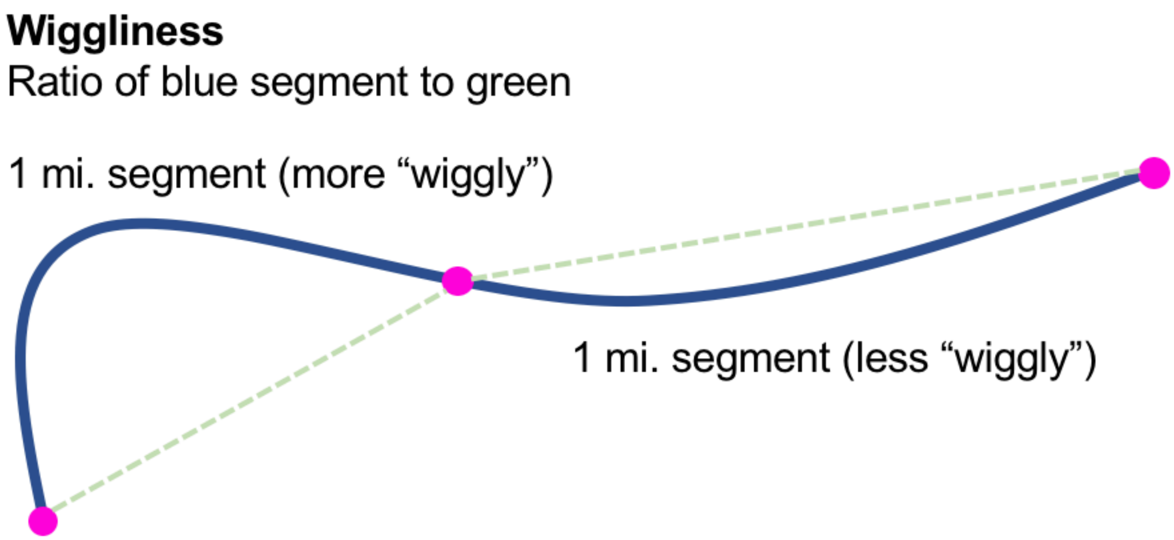
[57] For definitions, see U.S.C. 23 CFR §650.305 and the HPMS 2016 Field Manual (United States 2016).

which we matched to our dataset of Interstate segments derived from Nate Baum-Snow (FHWA 2016a; Baum-Snow 2007).

On the assumption that these structures are constructed in the same year as that of nearby segments' openings, we can measure the length of structures associated with nearby Interstate mileage. To account for mild spatial mismatch, we assign each (segment of) structure to its nearest highway segment within 250 meters. Segments of structures not within 250 meters of any highway segment aren't included. Our segment-level measure is then the sum of structure length divided by the segment length, and our state-period level measure correspondingly represents the ratio of all structure mileage to all Interstate mileage opened in the state and period.

u. Wiggliness

We measure the "wiggliness" (more formally, tortuosity) of a segment as the ratio of its true length to its length "as the crow flies" using our segment data derived from Baum-Snow (2007). These segments partition a high-fidelity map of the Interstates into approximately one-mile pieces. We generate the ratio of "wiggly" to straight length of highways by dividing this one-mile length by the (smaller) geodesic length between the segment's endpoints. Our state-period level measure is then the total "wiggly" length of mileage open in the given state-period divided by the total linear mileage opened in that same state-period.



v. Number of Interstate Lanes

We also measure the total number of lanes (across both directions) of Interstate mileage using data from the Highway Performance Monitoring System (HPMS) (FHWA 2016a). HPMS data is provided in a geographic shapefile of Interstate segments, as is our mile segment data derived from Nate Baum-Snow (FHWA 2016a; Baum-Snow 2007). Importantly, the HPMS data only gives lane counts for Interstate mileage as of 2016. To account for mild spatial mismatch between the two, we take, for a given Baum-Snow segment, the length-weighted average number of lanes across all HPMS segments nearer to the given Baum-Snow segment than to any other. We exclude from this average any HPMS segments with fewer than 2 recorded lanes. Our state-period level measure is then the average (weighted by Baum-Snow segment lengths) of these segment-level averages for all Baum-Snow segments built in the given state and period.

w. Time to Complete
To examine the relationship between the time to complete a segment of Interstate mileage from the start of construction, we used data reported on the FHWA's PR-511 forms, digitized and made available to us by Nate Baum-Snow (Baum-Snow 2007). These forms report the date a segment opened to traffic for 99.9 percent of funded segments for which we have data, as well as (for 51.9% of segments across all years) the date that construction started. The date of construction starting is indicated by a segment's movement from "Status Group 4" (indicating "[p]reparation of plans, specifications and estimates, and/or right-of-way acquisition") to "Status Group 3" ("under construction, not open to traffic") (Weingroff 2017c).

We have both pieces of data for a sample of the segments, ranging from less than 10% before 1960 and 40% in 1982 to just over 90% in 1972. We define completion time for a segment as the number of years between the open year and the year construction started. Our state-period level measure is then the segment length-weighted average completion time among all segments opened in the state and period for which we observe both the start and opening dates.

Appendix B - Cleaning Interstate Expenditures Measure

We measure spending on Interstates using the Interstate column in Table FA-3 of FHWA's *Highway Statistics* series. Changes in the Interstate funding laws and anomalies in the expenditure data, however, made us suspect that the Interstate expenditures from Table FA-3 were not all money spent on Interstates. The two changes were the introduction of the Interstate Withdrawal-Substitution Program and the requirement, starting in 1982, that all states receive at least half a percent of each year's apportionment—which we refer to as the Minimum Apportionment. In what follows, we outline the legislative history of these two programs, present evidence for why we suspect these two programs contaminate the Interstate column of in Table FA-3 and explain the changes we made to the Interstate expenditures measure to account for these two programs. Then we discuss the new Interstate expenditure measure and additional spending on Interstates that we may be missing.

I. Legislative History

a. Interstate Withdrawal-Substitution Program

The Interstate Withdrawal-Substitution Program came out of states' desires to deviate from the planned Interstate routes. The first such program was the Howard-Cramer Provision of 1968, which allowed states to withdraw planned routes and replace them with alternate routes of equal cost.[58] The Federal-Aid Highway Act of 1973 allowed the first substitution from Interstate highway projects to non-Interstate projects. States could withdraw planned highway segments in an urbanized area of the state and use the money instead for mass transit projects in the area.[59] The Federal-Aid Highway Act of 1976 altered the program so that States could also withdraw

[58] Public Law 90-238
[59] Federal-Aid Highway Act of 1973 (Public Law 93-87) Section 137(b)

Interstate segments connecting urbanized areas. It allowed them as well to use the money from the withdrawn portion for non-Interstate highway projects.[60]

Save for a slight modification in the Federal-Aid Highway Act of 1978 that prohibited the withdrawals of Interstate segments after September 30, 1983,[61] the next major change in the Withdrawal-Substitution Program occurred with the Surface Transportation Assistance Act of 1982. Before the passage of that law, the money from withdrawn segments was available to be obligated at any time.[62] After the passage of the 1982 law, the government made available set amounts of money each year for substitution projects. 25% of the funds made available each year were to be allocated at the discretion of the Department of Transportation. The other 75% of the money was allocated by formula: states were apportioned the fraction of the money that corresponded to the cost-to-complete estimates of their substitute projects as a fraction of the cost-to-complete estimates for all substitute projects in the country. States were apportioned this money via this formula for fiscal years 1984 through 1991. The money apportioned was available to be obligated for two years, after which the money apportioned would be withdrawn. Finally, the law allowed states to withdraw and substitute planned rural Interstate segments.[63]

The last change to the Withdrawal-Substitution Program came with the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). Section 1011 of the law apportioned money through fiscal year 1995 and also changed the apportionment rules so that all of the money would be allocated according to the formula based on the substitute project cost estimates of the states. The law made the money apportioned in 1995 available until obligated, meaning the previous two-year timer was not put in place for 1995. The fiscal year of 1995 was the last year in which the U.S. apportioned money to states for highway substitute programs.

b. Minimum Apportionment

The Minimum Apportionment rule in Interstate funding required that states receive at least 0.5% of the total money apportioned to all states every year. In general, if states had no more Interstates to spend the money on, they were allowed to spend the money on any other Federal-Aid highway. The rule was first put in place with the Federal-Aid Highway Act of 1970 for fiscal years 1972 and 1973, though the law did not specify what states could do with money that exceeded the cost to complete of their interstate systems.[64] Starting with the Federal-Aid Highway Act of 1973, highway legislation extended the Minimum Apportionment rule through fiscal year 1990 and specified that money apportioned under this rule that exceeded the cost to complete of the Interstate highway system could be spent on other Federal-Aid highways.[65]

The law left some ambiguity as to how the money apportioned under this rule would be tracked. The early laws pertaining to the Minimum Apportionment rule suggest that money that exceeded the cost to complete of the Interstate system would be reapportioned to the other

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[60] Federal-Aid Highway Act of 1976 (Public Law 94-280) Section 110(a)
[61] Federal-Aid Highway Act of 1978 (Public Law 95-599) Section 107(b)
[62] 1976 U.S. Code Title 23 103(e)(4)
[63] 1988 U.S. Code Title 23 103(e)(4)
[64] Section 105(b)
[65] The Federal-Aid Highway Act of 1973 Section 104(b) extended for fiscal years 1974–1976; the Federal-Aid Highway Act of 1976 Section 105(b)(1) extended for fiscal years 1978 and 1979; the Federal-Aid Highway Act of 1978 Section 104(b)(1) extended for fiscal years 1980–1983; the Surface Transportation Assistance Act of 1982 Section 103(a) extended for fiscal years 1984-1987; the ISTEA extended for fiscal years 1988–1990.

Federal-Aid highway categories. For example, Section 104(b) of the Federal-Aid Highway Act of 1973 states,

> Whenever such amounts made available for the Interstate System in any State exceed the cost of completing that State's portion of the Interstate System, the excess amount shall be transferred to and added to the amounts apportioned to such State under paragraphs (1), (2), (3), and (6) of subsection (b) of section 104 of title 23, United States Code, in the ratio which these respective amounts bear to each other in that State.

The law thus leaves the possibility that money given to a state under the Minimum Apportionment rule that exceeded cost-to-complete would not be considered “Interstate” money, but rather would be tracked according to the Federal-Aid category to which it was reapportioned. However, the Federal-Aid Highway Act of 1978 removed the language about reapportionment to simply say “the excess amount shall be eligible for expenditure for those purposes for which funds apportioned [for other Federal-Aid highway categories] may be expended,”[66] which leaves open the possibility that Interstate apportioned funds spent on other Federal-Aid Highways were considered Interstate expenditures for Table FA-3 purposes.

II. Issues in the Raw Data

a. Interstate Withdrawal-Substitution Program

FHWA’s *Highway Statistics* series contains a federal Interstate Highway Substitute expenditure variable in Table FA-3 and a federal Interstate Highway Substitute apportionment variable in Table FA-4. The apportionment variable starts in the first year of apportionment, fiscal year 1984, and continues through 1995. However, the federal expenditure variable for highway substitute projects begins in 1992. We think it is very unlikely that states only started spending money 8 years after they were apportioned it. It is more likely that FHWA only started tracking these expenditures in 1992.

We have good reason to believe that before 1992, expenditures on substitute projects were included in the Interstate expenditures measure in Table FA-3 of FHWA’s *Highway Statistics* series. Take, for example, Rhode Island. In our mileage data, the state last opened Interstates in 1976, when it opened 16 miles of highway. Rhode Island opened no new mileage after that. From 1977 to 1982, Rhode Island had two remaining Interstate projects. However, local opposition led the state to withdraw the planned mileage in 1982 (FHWAOE 1998). The projects it withdrew had a total withdrawal value of $592 million.

In the Interstate expenditure data, Rhode Island had very light expenditures (usually no more than $10 million a year) from 1977 to 1982. It is conceivable that these expenditures had to do with preparations for the two Interstate projects Rhode Island had left. After 1982, Rhode Island’s expenditures skyrocket—never dipping below $20 million from 1983–1985 and never dipping below $60 million from 1986 to 1991. These expenditures then collapse in 1992, when they fall below $20 million and quickly fall below $10 million. Rhode Island, though, opened no new Interstate mileage from 1977–1993. These massive Interstate expenditures in Rhode Island despite not having any remaining Interstate projects are strong evidence that money spent on substitute projects are included as Interstate expenditures in Table FA-3.

[66] Section 104(b)(1)

We checked the trends in Rhode Island's expenditure data against information from the FHWA's Office of Engineering 1998 report, which detailed all segments of the Interstate system that were withdrawn under the Withdrawal-Substitution Program. According to the report, Rhode Island obligated a total of $642.3 million dollars to substitute projects after withdrawing its Interstate projects in 1982 (FHWAOE 1998). Looking back at the Interstate expenditure FA-3 data, Rhode Island spent about $470 million on Interstate expenditures from 1983 to 1991 despite not opening a new mileage. Interstate expenditure collapse starting in 1992, and, conversely, Rhode Island spent $260 million on Interstate Highway Substitute expenditures in the years after 1992 (remember, this variable only appears starting in 1992).

A visual look can clarify the dynamics. Figure B1 below shows Rhode Island Interstate expenditures from 1970 to 1997 and Interstate Highway Substitute expenditures from 1992 to 1997. The solid line shows the last year in which Rhode Island opened new mileage, and the dotted line show the year in which Rhode Island withdrew its remaining planned Interstate mileage. After the dotted line, Rhode Island's Interstate expenditures surge until they collapse suddenly in 1992, when the Interstate Highway Substitute expenditures series begins. This evidence suggests that states' expenditures on substitute projects were classified as Interstate expenditures until 1992, when the Interstate Highway Substitute variable began. Evidence from other states that withdrew Interstate mileage supports this conclusion.

There is one caveat about the kind of substitute spending that shows up as an Interstate expenditure. Recall that the money made available from Interstate withdrawal could be spent on two types of projects: transit projects or non-Interstate highway projects. It appears that if the substitute money was spent on transit projects, the money did not show up as Interstate expenditures. As evidence, consider the case of Massachusetts. Massachusetts withdrew Interstate projects in 1974 and obligated around $1.5 billion dollars from this withdrawal to transit projects (FHWAOE 1998).

However, as Figure B2 shows, Massachusetts barely spent around $100 million a year from 1974 to 1987 while opening over 30 miles of Interstate. This means that if the amount spent on transit projects was counted as an Interstate expenditure, Massachusetts' true Interstate expenditure would be close to zero from 1974 to 1987, which seems unlikely given how many miles of Interstate they opened in that time period. Our best guess for what is going on is that the substitution money was counted as Interstate expenditure if it was obligated to highway substitute projects but not if it was obligated to transit substitute projects. There is evidence that this might be the case based on the law governing the Withdrawal-Substitution Program. The 1976 U.S. Code states that "sums obligated for mass transit projects shall become part of, and administered through, the Urban Mass Transportation Fund,"[67] meaning that the money was no longer considered highway money. It is therefore plausible that FHWA would not have recorded expenditures of money on transit substitute projects as Interstate expenditures while it would have recorded expenditures on highway substitute projects.

b. Minimum Apportionment

We would have hoped that if states spent Interstate apportionment money on things other than Interstates, then the expenditure would have been recorded in the corresponding category on which the money was spent rather than the Interstate expenditure FA-3 category. This does not appear to be the case. For example, North Dakota did not open new mileage after 1977 and had a

[67] Title 23 Section 103(e)(4)

cost to complete of their highway system of 0 since at least 1982 (DoT 1983). Despite that, the state regularly recorded yearly Table FA-3 Interstate expenditures above $10 million throughout the 1980s. Something similar occurs in Delaware, which regularly recorded yearly Interstate expenditures above $10 million in the 1980s despite having a cost to complete of 0 since at least 1982 (DoT 1983). For these reasons, we believe that if states received money as a result of the Minimum Apportionment rule, expenditures of this money were recorded as Interstate expenditures regardless of what they were actually spent on.

III. Accounting for the Data Issues as a Result of the Two Programs

a. Interstate Withdrawal-Substitution Program

From FHWA's Office of Engineering, we know exactly how much money each state obligated to substitute highway projects and when they withdrew their Interstates. Table FA-3's Interstate Highway Substitute expenditure variable tracks how much substitute money was spent after 1991 (FHWAOE 1998). We therefore know how much money must have been spent before 1991. Using Table FA-4's Interstate Highway Substitute apportionment data, we use an algorithm to determine how much expenditure by year should be removed from the Interstate expenditure variable to account for money spent on substitute projects.

Withdrawal-Substitution Algorithm

1. Calculate total amount apportioned for the Interstate Highway Substitute. This is a variable available from the years 1983 to 1994, meaning that it is the apportionments for the FY1985-1996.
2. Calculate total amount of Interstate Highway Substitute expenditure. This is a variable that runs from 1992 to 2014.
3. Calculate the amount that must have been spent in the years 1985 to 1991. This is Calculation (1) – Calculation (2). The idea is that if they were apportioned the money and did not spend it in the years after 1991, this must have been spent between 1985 and 1991. This idea might be a bit of a stretch, as the money could have been apportioned but never used. We assume this is negligible.
4. We impute the minimum amount spent (the reason why it's only the minimum amount will become clear later) on substitution projects each year from 1985 to 1991 using the following method.[68]
    a. Calculate the sum of apportionments for 1985 through 1991.
    b. Calculate the apportionment of each year from 1985 through 1991 as a percentage of Calculation (4a)
    c. Because apportionments in a few states drop off very quickly (much more quickly than expenditures. In fact, some substitution states get no apportionment for the last two years), if the percentage in any one of the years 1990 and 1991 is less than 5% then replace the amount in (4b) with 5%. The amount added to these years is removed from the other years in proportion to the amount in Calculation (4b).

[68] An alternate method we explore was to set this to be the average yearly amount of Calculation (3). However, sometimes this would lead to more money being spent than had been apportioned.

    d. Calculate the minimum amount spent on substitute projects each year by multiplying Calculation (3) by Calculation (4c).
5. Remove the minimum substitution amount results from Calculation (4) from the expenditure variable
6. Subtract Calculation (1) from the total amount obligated to highway projects (from FHWA OE 1998)
7. We determine the amount of expenditures that, when used as a ceiling for expenditures (adjusted by Step 5) from the date of withdrawal approval to 1991, removes enough expenditures from those years to account for the amount in Calculation (6).
8. Set the amount from Calculation (7) as the ceiling for expenditures from the year of first withdrawal to 1991.[69]

b. Minimum Apportionment

To account for non-Interstate spending as a result of the Minimum Apportionment rule, we used the Interstate Cost Estimates (ICE) produced by FHWA. These were 15 reports produced between 1958 and 1991 that were used to determine the distribution of each year's Interstate apportionment among the states. Crucially, states could only spend money apportioned for Interstate construction on other kinds of highways only if the amount they were apportioned in a given year as a result of the Minimum Apportionment rule exceeded the cost to complete of their Interstate system as a reported in the Interstate Cost Estimates. We use the cost to complete estimates from the ICEs to determine when states could have begun spending Interstate Minimum Apportionment money on non-Interstate projects and remove all spending that can plausibly be attributed as non-Interstate spending.

Minimum Apportionment Algorithm

1. Take the expenditures measure that has been cleaned of Withdrawal-Substitution spending
2. For the years in which the Minimum Apportionment Rule was in effect (1982 and on), impute the cost to complete (C2C) as reported in the ICE. The ICEs were not produced every year but rather only when requested by Congress, which was usually every two or three years. To determine the cost to complete of a state's system in a year in which an ICE was not produced, we multiply the previous year's cost to complete by the fraction of miles not yet completed at the end of the current year out of the number of miles not yet completed at the end of the previous year.
3. Identify the years in which the interpolated C2C was less than the amount apportioned for that year.
4. If a year x satisfies (2), then replace that year's Interstate expenditure with [year x C2C - year $x-1$ C2C] (that is, the amount by which the estimated C2C decreased), so long as that value is less than the given state's spending in year x.
5. For the small number of cases in which miles are built after the C2C is 0, we assume negligible spending on those miles after the C2C went to 0, so we reassign the miles to the last year in which miles were opened before C2C went to 0.

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[69] There are two reasons why we consider expenditures from date of withdrawal to 1991 and not just until 1983. First, money can be spent many years after it is obligated. Second, states could have received money from the 25% discretionary fund of FHWA, not just the apportionments by formula (see Section I(a) of this Appendix).

6. Since Interstate Cost Estimates only go until 1990, we assume that the Interstate Cost estimate for 1991, 1992, and 1993 is also 0 if 1990 is zero. Otherwise, we make no guesses about the Interstate Cost Estimate. Therefore, we make no changes in expenditures for states for which the 1990 C2C is more than zero.

IV. Results

Figure B3 below shows the evolution of the Interstate expenditure measure as we account for the Withdrawal-Substitution program and the Minimum Apportionment rule. The blue line represents the original Interstate expenditure measure from the *Highway Statistics* series. The red line shows the Interstate expenditure when the highway substitution spending is accounted for, and the green line shows expenditures when both highway substitution and the minimum are accounted for. The lines begin to diverge in the mid-70s, but the period of largest divergence occurs in the second half of the 80s.

Figure B4 shows the share of the original total U.S Interstate real expenditures removed by accounting for the Withdrawal-Substitution Program and the Minimum Apportionment Rule. The share removed due to the Substitution program is less than 10% each year from 1977 to 1984. After 1984 there is a surge in the removal, with the share removed as a result of the Substitution program never dipping below 10% through 1991. Since the Interstate Highway Substitute variable in the *Highway Statistics* series starts in 1992, there is no more removal as a result of the Substitution program after 1991. The amount of real expenditures purged due to the Minimum Apportionment program is smaller than the amount removed by the Substitution program, but its influence grows over time. In total, the share of real expenditures removed by the Substitution program from 1977 to 1993 is 7.7%, while the share removed because of Minimum Apportionment rule is 3.0%

We make a couple of notes about the final expenditure measure. First, it is much more reliable when considered over a period of years than when considered on a year-by-year basis. While we know how much a state that substituted spent on highway substitution, we do not know exactly how much was spent each year on substitution projects. Our method for dealing with this issue depended on the year of the money spent, but it required either assuming that a year's substitute expenditure was correlated with that year's apportionment (see step 4 in the Substitution algorithm) or assuming that the years of highest expenditure between the year of withdrawal and 1991 were the years that contained the substitution expenses. Neither of these approaches guarantees that we will pin down the correct substitution expenditure in a given year.

Second, we may be overestimating the amount to be removed as a result of the Minimum Apportionment program. Our method for dealing with the minimum issue is to use the Interstate Cost Estimates from FHWA. When a state begins to receive more in apportionment than they need to complete their interstate system, we replace its expenditure with the (imputed, based on completed mileage) change in that state's estimated cost to complete as reported in the ICE. If there were cost overruns in a state, then we would be underestimating the amount of actual Interstate expenditure in that state. The effect of this measurement error is likely to be very small, as the states to which this measurement error applies were spending a relatively small amount to begin with. Finally, as we will explain in the next section, we may be underestimating the amount spent on Interstates because of the 85%-90% allocation rule.

V. Minimum Federal-Aid Percentage Allocation

Similar to the Minimum Apportionment rule, the Minimum Federal-Aid Percentage Allocation required that the sum of all federal aid funds given to states in a given year be at least a certain percentage of the amount of taxes the drivers in that state paid towards the Highway Trust Fund in the fiscal year with the latest available data. States in which the funding formulas for the different kinds of federal-aid funding produced apportionments that were lower than the minimum percentage of taxes paid to the Highway Trust Fund received an additional apportionment that would cover the difference. Money apportioned as a result of this rule could be spent on any road that was eligible for federal-aid funding. The rule was first put in place in fiscal year 1982, when the minimum percentage was set at 85%. That minimum percentage stayed until 1992, when it was increased to 90%.[70]

The *Highway Statistics* series tracks the amount of money apportioned due the minimum percentage rule as a separate variable. It also tracks the expenditure of this money separately from the spending of the specific categories. We therefore cannot know what category of Federal-Aid the money was spent on—it could have been spent on Interstates, but it could have also been spent on Federal-Aid Primary, Secondary, or Urban roads, among others. As a result, we very likely underestimate the amount of money spent on Interstates. In addition to not knowing how much of the money was spent on Interstates, it is difficult to remove the effects of this money since the time between obligation and expenditure is uncertain, and the states could just have not obligated the money at all. Between 1982 and 1994, no more than 19 states received an apportionment under the minimum percentage rule in any given year, with at least seven states (not necessarily the same states) receiving the money every year. From 1982 to 1993, expenditures of money apportioned as part of the minimum apportionment rule were 20.6% percent of the cleaned measure of Interstate highway expenditures. From 1982 to 2014, the corresponding percentage was 29.2%.

[70] The exact wording and yearly requirements are in the Highway Improvement Act of 1982 Section 150(a) for fiscal years 1982–1986. For fiscal years 1987 onwards, they are contained in the 1994 U.S. Code Section 157(a).

Figure B1

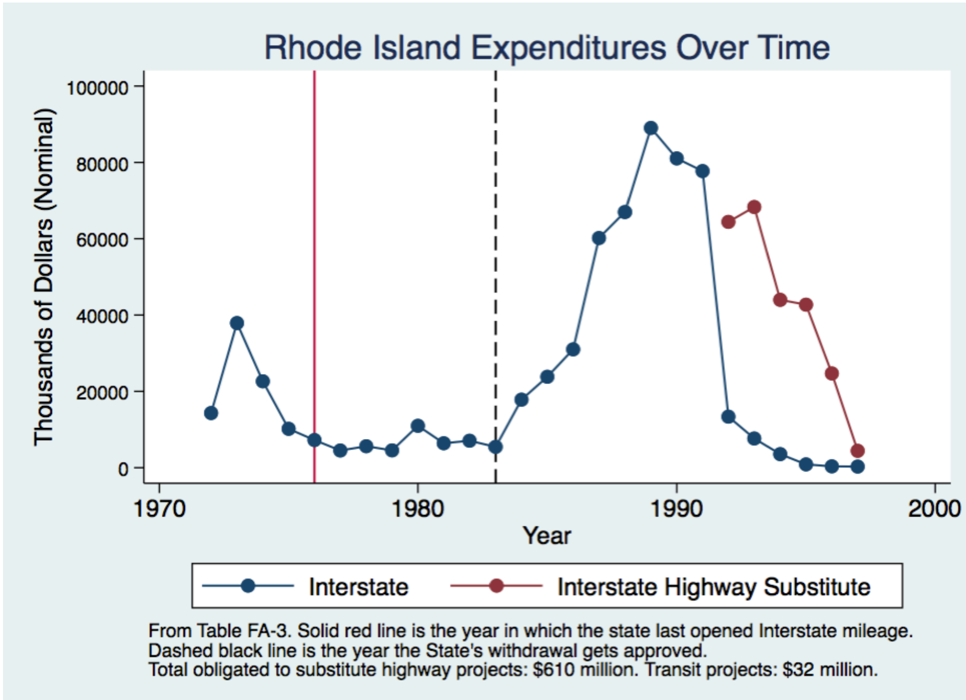


Figure B2

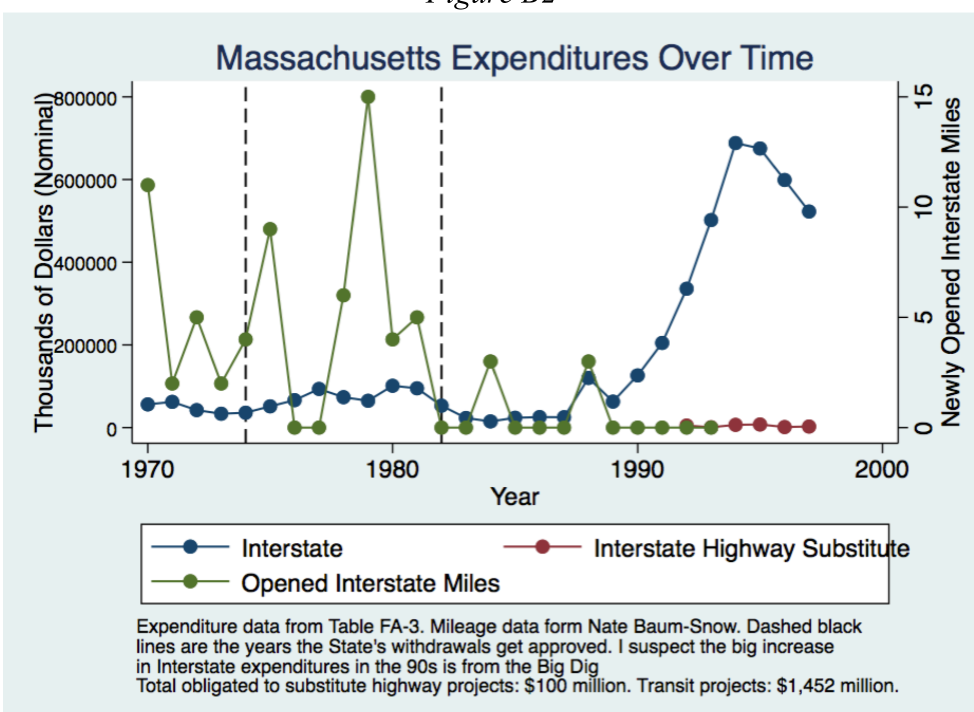


Figure B3

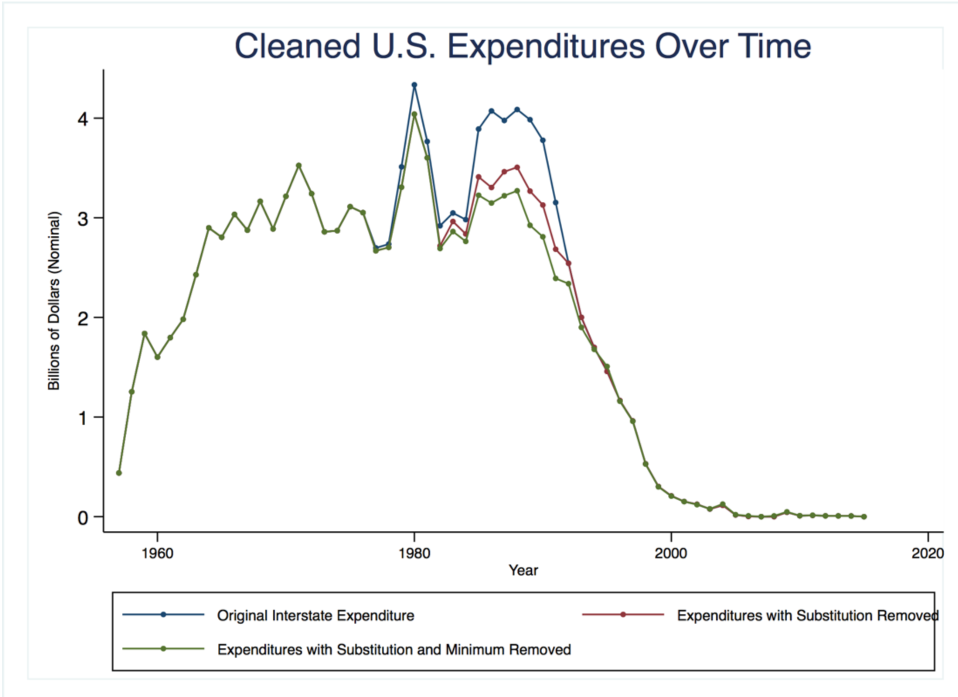
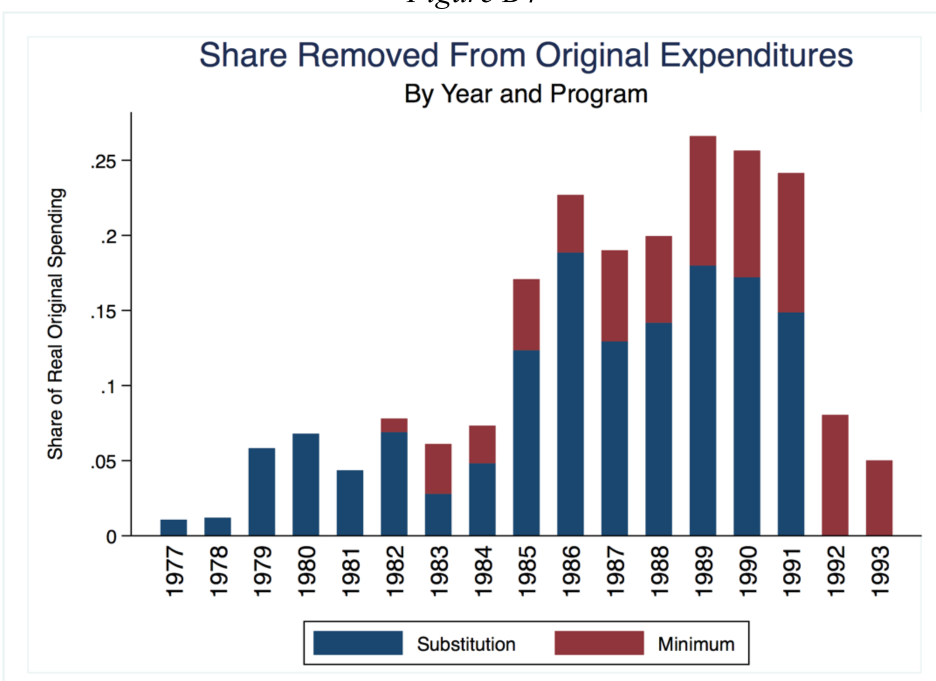


Figure B4



Appendix C - More on Interstate Funding

Once apportioned, Interstate funding 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 state for the eligible portion of a project's cost. To obtain an obligation, states[71] 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.[72] 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.

[71] 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)).

[72] 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).