Procurement and Infrastructure Costs

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Abstract

Why is building and maintaining infrastructure so expensive in the United States? We collect new project-level data on infrastructure spending and new survey data on how the states procure these projects. This allows us to document variation in costs between states, and then correlate these costs with potential cost drivers. We find that two important inputs in the procurement process appear to particularly drive costs: (1) the *capacity* of the DOT procuring the project and (2) the lack of *competition* in the market for government construction contracts. We quantify the role of capacity with administrative data that links individual personnel with infrastructure contracts in California. We show that higher quality engineers deliver projects at a lower cost, while retirement shocks slow project timelines and increase costs.

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1 Introduction

There is growing concern about the cost of building infrastructure in the United States. For urban rail, the US is about three times as expensive as other rich countries (Goldwyn et al., 2023; Liscow, 2024). The cost of building one mile of interstate highway tripled between the 1960s and 1980s, and continued to increase afterward (Brooks and Liscow, 2023; Mehrotra et al., 2021). Despite the size of the expenditure, engineers have emphasized the poor state of US infrastructure (American Society of Civil Engineers, 2021).[1]

The government itself does not build rail and roads; instead, it procures them: drawing up project plans, putting the project out to bid, and supervising the work that private sector firms complete. Understanding the procurement process may be key to understanding infrastructure costs; for example, the design and implementation of procurement auctions can have implications for winning bids and final costs (e.g. Krasnokutskaya and Seim, 2011; Lewis and Bajari, 2014) and the identity of bureaucrats that procure projects can have implications for the final prices paid (e.g. Bandiera et al., 2021; Best et al., 2023). While the literature provides evidence in particular settings for which rich data exist, there is no comprehensive data on either costs or the range of procurement practices to assess whether differences in procurement practices—previously studied or not—explain variation in costs across states.

In this paper, we embark on an ambitious data collection effort to study infrastructure cost drivers. We produce two new datasets that will be valuable resources for future research in this area. The first dataset documents the cost of resurfacing, at the project level, across U.S. states. The second dataset documents the process by which each state manages the procurement and delivery of these projects. We then combine the two datasets and use variation across the states to explore the correlates of infrastructure costs. We find that state capacity and competition in the market for projects, instead of any specific procurement rule, are important drivers of realized costs. In the final part of the paper, we use administrative data from one large state to further quantify the role of state capacity in this setting. We show that individual engineer quality can significantly reduce costs at the project level, while retirement shocks at the district level lead to longer project timelines and higher costs.

We start with the basics. How much does it actually cost to resurface a road in the United States? There is no centralized dataset on infrastructure project costs, even for federally funded projects. Instead, the Federal Highway Authority requires states to report aggregate spending in var-

[1]The fact sheet for the 2021 Bipartisan Infrastructure Law, which allotted an additional $110B of federal funds to road and bridge improvements, states that "1 in 5 miles of highways and major roads, and 45,000 bridges, are in poor condition." See `https://www.presidency.ucsb.edu/documents/fact-sheet-the-bipartisan-infrastructure-deal`.

ious categories. Differences between states in the number and scope of projects they complete, as well as differences in reporting, mean that the aggregate data is not particularly useful for understanding cost drivers. To this end, we create a new dataset on *project-level* costs for each state. We collect this data state-by-state via public records requests. Then, we match the contract data with project plans and bid lettings, in order to create a cost per mile measure that is comparable across states. We find substantial variation in resurfacing costs; states that are similar in geography, climate, and highway network have large differences in cost per mile. To verify the data quality, we show that the cost data we collect is correlated with observables that should drive costs (weather, road usage, labor costs). In fact, observables at the project, local, and state levels explain about 35% of the variation in costs across projects. Strikingly, publicly available data on aggregate resurfacing costs from the Federal Highway Administration do not correlate with these observable cost drivers.

Next, we link our new data on costs to potential cost drivers, with a focus on project procurement and delivery.[2] To create our procurement policy dataset, we conduct a 50-state survey of state Department of Transportation (DOT) highway procurement practices. We survey two groups in each state who have complementary knowledge about state procurement: procurement officials at each DOT and contractors (i.e., road builders and engineers at private firms). The survey asks specific questions about rules and practices, all of which can be related to potential cost drivers in the project procurement and delivery process.

The issue of data and measurement is first-order to the question of infrastructure spending. Following a New York Times investigation on subway costs in New York, Congress directed the Government Accountability Office (GAO) to publish a report on why transit projects in the United States were more expensive than transit projects in other developed G-20 nations (Rosenthal, 2017, 2018). The GAO ended up running into significant difficulties, and was not able to say much about cost drivers, citing data limitations and the complexity of transit projects as the main impediments. In this paper, we ask the same question: what is driving U.S. infrastructure costs? However, instead of focusing on transit and the international comparison, we focus on the cost of highway resurfacing across U.S. states.[3]

Resurfacing projects are much smaller than megaprojects that have been the focus of recent academic work (i.e., Fajgelbaum et al., 2023; Gupta et al., 2020). However, they are the bread and butter of American infrastructure spending. Total capital transit spending across the U.S. is an order of magnitude less than highway spending.[4] And, however challenging procurement is for resurfacing,

[2]Every federally funded road building and resurfacing project goes through a procurement process, usually an auction.
[3]See the Transit Cost Project (Goldwyn et al., 2023) for an excellent comparison of transit across countries.
[4]In 2022, the Federal Transit Administration reported an expenditure of $27 billion across all transit authorities,

it is likely even more challenging for more complicated projects, which also must be procured. Most importantly, focusing on a project that is relatively simple, like resurfacing, allows us to create apples-to-apples comparisons—avoiding the pitfalls that come with trying to compare complex projects with multiple different components in different settings. Every state is resurfacing their roads, so we can use the states as a laboratory. We compare costs across states and explore the differences in state practices, policies, and markets that can potentially drive these costs.

The evidence points to two broad patterns. The first is that state DOTs have increasingly limited capacity. There is broad agreement that state DOTs struggle with staffing and that reliance on consultants drives up costs. We confirm that the state DOT workforce has been shrinking with U.S. Census data on public sector employment; total highway employment decreases about 20% between 1997 and 2020. Further, when we measure capacity using the Census data, we show that states with higher DOT employment have lower infrastructure costs. Adding one state DOT employee per 1,000 residents (about 1.6 standard deviations) is correlated with 26% lower costs at the project level.

Survey questions related to capacity also correlate inversely with costs. As an example, states where contractors and procurement officials expect more change orders (ex-post changes to the materials and work needed to complete the project) have significantly higher realized costs. Frequent change orders directly lead to higher costs through delays and costly renegotiation; they also are a downstream symptom of poor administrative capacity—many contractors reference poor-quality project plans made by third-party consultants or inexperienced employees. Consistent with this, we find that costs are lower when the DOT provides more detailed project plans to bidders. Finally, we collect data on the page length of the documents that bidders must respond to in each state as a proxy of administrative burden; a one standard deviation (80-page) increase is associated with 16% higher costs.

The second set of results relates to competition. A lack of competition for contracts is an oft-cited cost driver from procurement officials. We show, with U.S. Census data on the highway construction industry, that concentration in the industry seems to be rising. Most states have experienced a loss of construction firms, and an increase in size of the remaining firms, in the last 10 years. In the survey data, we find that states that do outreach to increase the bidder pool have significantly lower costs, highlighting both the importance of competition and the role the DOT can play in increasing competition. In the project-level data, we find that an additional bidder on a project is associated with 8% lower costs per mile, conditional on the estimated cost calculated by the DOT. We also find that limits on the amount of work that can be subcontracted is positively correlated with

compared to $266 billion on highways in the same year (Federal Transit Administration, 2022).

costs. Restrictions on subcontracting can decrease competition by limiting the set of potential prime contractors that can complete the project. In order to probe this relationship, we collect data on the subcontracting requirements at the project level. We see that projects with more subcontracting requirements also end up costing more to the state, but that this correlation is attenuated in states where the market for qualified subcontractors is thicker.

In the final part of the paper, we exploit variation in capacity arising from both the assignment of individual engineers to projects and from quasi-experimental engineer retirements, across the state of California. Both analyses allow us to quantify the role of capacity, as measured by employee quality and experience, on realized costs.

First, we find that a one standard deviation increase in our engineer "quality" measure correlates with an 11% decrease in costs per mile, if the engineer is the project manager. Costs are further reduced when both the project manager and the engineer that oversees the construction phase are high quality. This result suggests that employee quality is an important input through the multiple phases of project delivery, but that the benefit of quality engineers in the construction phase may be constrained by earlier decisions and inputs in planning and design.

Next, we pair data on engineer retirements from state pension records to district-level cost and productivity measures. We find that increases in engineer retirement levels within a Caltrans district are associated with increases in duration, total cost, and cost overruns for projects let in the same year. A retirement shock equivalent to one percent of a district's staff engineers coincides with a 3.2% increase in project duration, a 4.3% increase in project costs, and a 5.6% increase in cost overruns, at the mean. These results are driven by retirements of engineers that deliver Caltrans projects, instead of upper levels of management.

Related Literature Our finding that procurement costs are highly correlated with DOT capacity is consistent with a literature on bureaucratic competence and capacity, both in the United States and abroad. Best et al. (2023) find that variation across individual procurement officials and agencies can explain a significant amount of variation in prices paid for goods in Russia. In a stylized model of the procurement process, they show that a bureaucracy can drive up prices by imposing higher contract fulfillment costs and by imposing higher participation costs, thereby reducing the number of bidders.[5] In our setting, bureaucrat effort after the auction is also a relevant input, as the government engineers oversee the post-auction (construction) phase of the project. In fact, we find that the engineers that oversee the construction phase can further meaningfully reduce costs, but only when they are paired

[5]Similarly, Bandiera et al. (2009) find that different agencies in Italy pay very different prices for the same products.

with a higher-quality project manager. This suggests that the competence of the construction engineer may be constrained by the project planning and bid-letting phases that occur before the construction begins.

Our findings on the effect of retirements on infrastructure procurement outcomes is consistent with previous work in federal procurement settings (Decarolis et al., 2020; Giuffrida and Raiteri, 2023; Warren, 2014). We depart from the literature by focusing not only on the mechanical effect of retirement on employee workload, but the effect of the loss of experience and expertise with the departing employee. The striking decrease in state DOT employment over the last 20 years, especially in the wake of the Great Recession, may have significantly contributed to rising costs (US Census Bureau, 1997-2021).

Our survey is inspired by the World Bank Doing Business Procurement Survey, which surveys procurement practices and law across *countries* (Bosio et al., 2022).[6] In developing the survey, we benefit from a rich empirical auction literature that studies how the design and implementation of procurement practices can have implications for costs. Researchers have studied highway procurement auctions in specific states, and focus on different aspects of the auction design or procurement process. For example, Jofre-Bonet and Pesendorfer (2003), Krasnokutskaya and Seim (2011), and Bajari et al. (2014) all use data on highway auctions in California, but study the role of capacity and the timing of bid-letting, bid preference programs and entry, and contract incompleteness, respectively. De Silva et al. (2008) and Barrus and Scott (2020) both study information provision, but in different states; De Silva et al. (2008) find that when the DOT provides more information to bidders, in the form of detailed plans, costs decrease (in Oklahoma), while Barrus and Scott (2020) find that providing more information, in the form of the identity of competing bidders, leads to increases in costs (in Kentucky).[7] Our new survey data allows us to uncover important suggestive findings that would not have been attainable from studying quasi-experimental variation in particular auction practices

This paper contributes to a burgeoning literature on the U.S. construction industry, and infrastructure construction in particular. Goolsbee and Syverson (2023) have documented a large and long decline in construction sector productivity. Kroft et al. (2022) show that construction firms have considerable market power: in both the labor and the product market. On the infrastructure side, Brooks and Liscow (2023) find suggestive evidence that increases in costs in road building in the later

[6]The authors find that correlations between procurement practice and outcomes highlight the importance of public sector capacity, while regulations only become more useful in countries more vulnerable to corruption. We do not find any role for corruption as a cost driver in the U.S. context. However, public sector capacity remains important in our setting.

[7]We provide a more in depth review of the literature, and how this literature links to specific hypotheses about procurement and costs, in Appendix A.

part of the 20th century were driven by citizen voice, which delays the building process, instead of increases in materials or labor costs. Mehrotra et al. (2021) find that input prices are more important for resurfacing, over time. This paper adds one important piece to the understanding of the interaction between the DOT and the private sector: the procurement process.

There is also a small, but growing, literature that focuses on the supply side determinants of procurement costs. Our findings on the role of competition contribute to a debate on the relationship between the number of bidders and costs in the procurement setting. Coviello and Mariniello (2014) find that increased publicity increases auction participation and lowers costs to the government; larger and less local firms are more likely to win auctions that are publicized. However, Carril et al. (2022) find that while publicity increases the number of bidders and lowers winning bids, ex-post contract performance decreases, leading to delays and cost overruns. Finally, Allende et al. (2023) use a natural experiment to study the effect of an increase in auction participation on prices in public procurement of pharmaceuticals in Chile, and find that the entry of an additional bidder decreases costs by about 10%.

Our paper proceeds as follows. Section 2 introduces the new dataset of resurfacing costs across the U.S. states. Section 3 provides background on the procurement process for the typical project in our data, and goes through the details of the survey design and distribution. Section 4 introduces descriptives from the survey, with a focus on what survey respondents think drive costs. We correlate the survey responses with the cost data, and then provide additional evidence from auxiliary data sources, in Section 5. Section 6 provides quasi-experimental evidence of the role of capacity using data on engineer quality and retirements, and Section 7 concludes.

2 Project-Level Data on Costs

The first step to understanding cost drivers is to accurately measure costs. Unfortunately, no such comprehensive dataset exists; the federal government does not require states to report project-level costs on federally funded projects.[8] Therefore, most research on the topic uses aggregate (state-level) spending, or detailed bid data from one state.[9] We need detailed project-level data in order to facilitate a comparison of similar projects across states.

We collect project-level cost data by requesting administrative data from each state DOT, via

[8] An exception is for projects funded in the ARRA, but this is 10 years before the period of interest.

[9] The Federal Highway Administration data aggregate spending data is submitted by the states, and each state can determine how to account for projects over categories and time. Therefore, there are concerns over different norms across states in categorization of work-type or in the accounting of multi-year projects. Further, there is no concept of the quantity of work done, only the spending is reported.

public record requests. We are able to obtain project-level cost data from all 50 states, though the number of observations we have from each state varies. The data we receive from the states generally include the winning bid for the contract, a brief description of the project (or at least a project identifier we can link to the bid letting or project plans), the final cost of the project, the award date, and the completion date.[10] We also collect data on the scope of each project, allowing us to calculate cost per lane mile.[11]

To facilitate cost comparisons across projects and states, we construct a subsample of projects meeting predetermined criteria. Our goal is to create a sample of projects that are similar to the representative project described in the survey case study. Specifically, we randomly select 5 projects from each state that satisfy the following criteria: 1) classified as "resurfacing," 2) started in 2018 or 2019, 3) project length between 1 and 20 miles, and 4) a state or U.S. highway (non-interstate) project. Along with facilitating more direct comparisons, focusing on a smaller number of projects in the subsample allows us to gather more detailed information about the nature of work for each project. We are able to fill in fields that are missing from the administrative data—such as the number of bidders for each project, the Disadvantaged Business Enterprise (DBE) threshold for the project, and any non-standard work that the project included—through examining the individual bid-lettings and project plans. In Appendix B we discuss an example project from our data, and the pieces of information we collected about the project, to give the reader some additional context.

Figure 1 shows the distribution of cost per mile at the project level.[12] The majority of projects in the subsample (95%) cost under $1 million per mile; average cost is about $368,000 per lane-mile, and the median is $226,000 per lane-mile. The 25th percentile is $131,000 per lane-mile, and the 75th percentile is $417,000. Additionally, there is substantial variation in average costs across states. For example, cost per mile is twice as expensive in South Carolina as in the neighboring states of Georgia and North Carolina.[13,14] The point of this paper is to understand what drives these differences.

We use cost per mile as our primary outcome of interest, though in the analysis we can consider other outcomes, such as project duration. This is a departure from some focus of the literature and policy discussion, which uses cost overrun as the measure of project success or costs. However, cost

[10] For some states, we only observe the winning bid. However, for 75% of states we observe both the winning bid and the realized cost. Appendix Figures D.1 and D.2 show that there is a tight relationship between bids and realized costs for these type of projects.

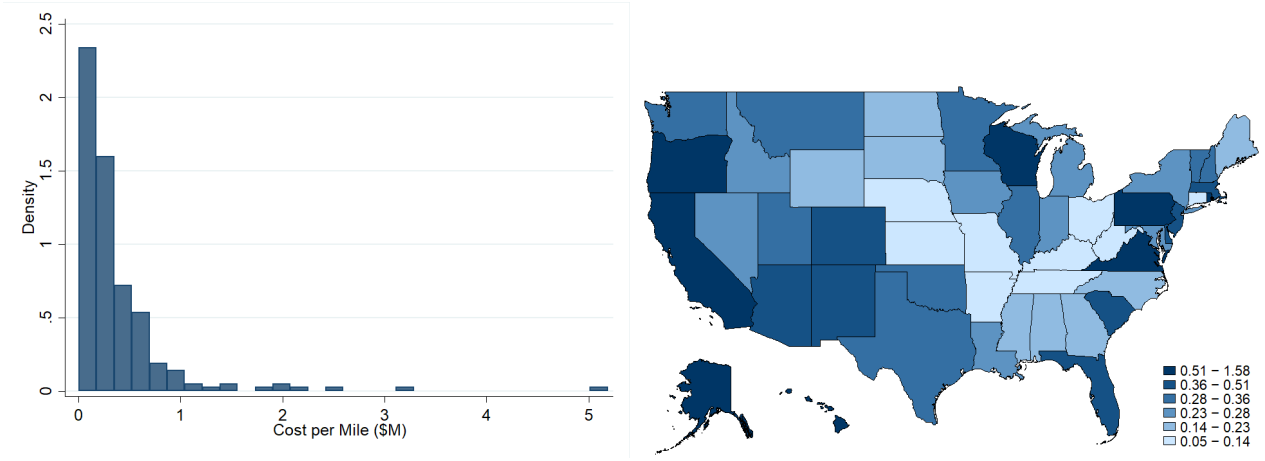
[11] Some states include mileage in the data they provide. For many others we use the bid-lettings or project plans that are associated with the specific project. Specifically, we calculate the lane-mileage for each project, which takes into account both the length and width of the project.

[12] Our measure of cost per mile is the total cost of the project divided by the lane-mileage of the project.

[13] Appendix Figure D.3 shows that the majority of the subsample contracts have a contract size of under $5 million, as was specified in the case study.

[14] Appendix D.1 provides more details on data collection and descriptive statistics.

Figure 1: Resurfacing Costs per Mile ($M)



(a) Project-Level Cost per Mile ($M)

(b) State-Level Cost per Mile ($M)

Notes: The figure on the left shows the histogram of project-level resurfacing costs per lane-mile. The figure on the right takes the average of project costs at the state level. There are 250 projects in the sample: 5 projects per state. Data collected by the authors.

overruns only capture costs in excess of bids, which ignores an important input to the high cost of infrastructure procurement: the cost quoted by the contractor when they bid for the project. If all of the bids are high, a project with no cost overrun will still be expensive for the DOT to complete. Therefore, we use the *total* realized cost for our cost measure, which is the winning bid plus any changes that are incurred during the construction phase (i.e. the overrun).

2.1 Observables and Costs

Table 1 shows the relationship between project-level resurfacing costs and established cost drivers, which include project-level details, local characteristics, and weather.[15,16,17] The standard errors are clustered at the state level, and we have 5 projects per state, as discussed earlier in this section.

The project-level details include a dummy for whether the project involves non-standard work in addition to the resurfacing (we call this "Complex"), the size of the project ("Lane-Miles"), and a dummy for whether the project is on a state highway, as opposed to a US highway ("State-Highway"). Column (1) shows that as expected, the complex projects are more expensive. There are also fixed costs of resurfacing: longer projects cost less per lane-mile, which is consistent with discussions we have had with highway engineers.

[15]Descriptive statistics for all of the variables are displayed in Appendix Table C.1.
[16]External data sources are described in Appendix F.
[17]We talked on background to many helpful DOT engineers to verify the established cost drivers.

Table 1: Project Costs and Observable Cost Drivers

	Project-Level Log(Cost/Mile)				State-Level Our Data	State-Level FHWA
	(1)	(2)	(3)	(4)	(5)	(6)
Project Details:						
Complex Dummy	1.027***	0.932***	0.818***			
	(0.270)	(0.281)	(0.282)			
Mileage	-0.023***	-0.024***	-0.023***	-0.067***		
	(0.006)	(0.004)	(0.004)	(0.011)		
State Highway Dummy	-0.234*	-0.067	-0.046	-0.048		
	(0.133)	(0.127)	(0.122)	(0.127)		
Local Characteristics:						
Log(Population Density)		0.067+	0.052	0.067		
		(0.040)	(0.041)	(0.049)		
Log(Wages in Hwy Construction)		0.344*	0.064	0.174		
		(0.196)	(0.176)	(0.268)		
State Characteristics:						
Precipitation		-0.033***	-0.032***	-0.028***	-0.035***	-0.000
		(0.007)	(0.006)	(0.006)	(0.009)	(0.006)
Winter Low		0.055***	0.041***	0.038***	0.050***	-0.007
		(0.011)	(0.010)	(0.012)	(0.018)	(0.009)
Snow Proxy		0.021+	0.019	0.022+	0.204*	-0.014
		(0.014)	(0.015)	(0.014)	(0.107)	(0.080)
Summer High		-0.057***	-0.039*	-0.035*	-0.047**	-0.015
		(0.021)	(0.021)	(0.019)	(0.022)	(0.015)
Roughness Index			0.017***	0.013**	0.024***	-0.001
			(0.005)	(0.006)	(0.005)	(0.004)
Observations	250	250	250	2,210	49	49
R-squared	0.18	0.35	0.39	0.31	0.39	0.11

Notes: This table presents a simple regression of resurfacing costs on observable cost drivers. The first three columns use the subsample of 5 projects per state. Column (4) uses all of the project-level data we have, which varies by state. The results in Column (4) are weighted so each state is equally represented. We are not able to collect lane-mileage or local population density for every project in the full sample, so we use the cost per mile instead of lane-mile, and we use the state-level population density. Columns (5) and (6) aggregate the data to the state level, and compare the fit of our cost data to that of the FHWA spending on resurfacing and maintenance per vehicle mile. Alaska is excluded. The project-level costs and characteristics are collected by the authors, and the data on other observables is described in detail in Appendix F and in the table notes of Appendix Table C.1. Standard errors are clustered at the state level. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15.

In Column (2) we add state and local characteristics that can affect resurfacing costs. This includes labor inputs, as measured by local wages in the "Highway, Bridge, and Street Construction" industry.[18] We find that wages are positively correlated with costs, as expected. Our other local variable is population density in the county of the project. Population density is also positively correlated with costs. This could be due to both road use, which affects the amount of work needed to be done for the resurfacing job, and the additional costs of traffic stoppage and diversion during

[18]This industry classification (NAICS 2373) includes new work, reconstruction, rehabilitation and repairs, so it is not exclusively resurfacing industry wages, but would encompass the wages paid for the projects in our database. We measure wages at the MSA or county level (using the smallest aggregation that is available).

the project completion. The next set of variables capture the climate of the state. States with more snow and longer winters tend to have higher costs, due to the shorter window that contractors have to complete the jobs, the toll the salt takes on the roads, and the damage to pavement from repeated freezing and thawing. Costs are higher in states with more snow and lower in warmer states.[19]

In Column (3), we add state-level measurements of road roughness. FHWA mandates that states collect these data annually; it measures the total vertical deviation from smoothness in an average kilometer.[20] We add this index to capture the fact that rougher, more damaged roads require more intense resurfacing work, which is likely to be more expensive.[21] Indeed, we see that states with rougher roads have higher costs, and that roughness captures some of the correlation between weather and costs.

In Column (4) we include all of the data that we collected from the states, not only the analysis subsample. This regression is weighted so that each state is represented equally. There are 22 states where we have more than 5 resurfacing projects that fit our sample selection.[22] This ranges from less than 10 projects in AZ, CO, and NY, and more than 200 projects in KY, PA, and TX. The drawback is that we do not have project-level details for all the sample, so we cannot add the complexity dummy and we cannot always identify the county of work, instead using the state-level population density and wages. However, we are encouraged that the results are consistent with the results with 5 projects per state; our subsample data is reflecting true patterns in underlying costs across U.S. states. The correlation at the state level between the subsample and full sample is high: 0.67 for mean cost per mile and 0.78 for median cost per mile (Appendix D.2).

2.2 Comparison with Federal Highway Statistics

Columns (5) and (6) compare our cost data with the Federal Highway Authority (FHWA) Highway Statistics data. For this analysis, we average our data at the state level because the FHWA data are only available as a state-level aggregate. For closeness of comparison, we take resurfacing and maintenance cost series from FHWA, from 2014, 2018, and 2019.[23] One challenge in using the FHWA

[19] We do not have a direct measure of snowfall but proxy this with the average precipitation in the state multiplied by the inverse of the winter high temperature.

[20] This is the International Roughness Index, and we use the average of the roughness measure from 2014, 2018, and 2019. Currier et al. (2023) point out significant issues with FHWA's roughness measurements for minor arterial roads, and highlight its lack of availability for local roads. The roads in our sample tend to be major arterial roads, which should suffer from less roughness measurement error.

[21] Pavement with extensive damage must undergo a "mill-and-fill," in which several inches of asphalt are removed and replaced. Pavement in better condition can receive a cheaper treatment such as a chip seal, in which a new, smooth layer of asphalt is applied to the top of an existing layer and topped with crushed rock.

[22] As a reminder, we create a sample of non-interstate highway resurfacing projects starting in 2018 or 2019, with a length between 1 and 20 miles.

[23] This data is not available for 2015-2017. See Appendix D.3 for more details for the construction of the series.

data is while it reports costs, it does not report the amount of work completed. We divide the spending by the vehicle miles, as a proxy for the amount of resurfacing and maintenance work completed.[24] The table shows that while our data, when aggregated, still is highly correlated with state-level weather and road roughness, there is no relationship between these variables and the FHWA data, probably because of widely varying reporting standards across the country (Liscow, 2024). This is also confirmed in the scatter plots in Appendix Figure D.9.

We also compare the FHWA cost totals to cost totals in our data for California, a state where our data covers nearly all DOT projects.[25] Between 2015 and 2019, the total spending observed in our data is $28.1 billion and the total spending observed in the FHWA data is $24.9 billion.[26] These comparisons bolster our confidence that the project-level cost data that we collected consists of the individual projects underlying the aggregate FHWA data series. In short, the micro data we collect is the input to the aggregate FHWA data series, but having this data at the project level allows us to go much further in the analysis of potential cost drivers, because we can compare similar projects across states.

3 Procurement Survey

As background, we provide a brief overview and timeline on the state DOT procurement process for a standard resurfacing project. Then, we proceed with details on the survey design and distribution.

3.1 A Brief Procurement Primer

Pre-Bidding: Before the bidding starts, the DOT plans the project. The agency determines the scope of the work, and a DOT design engineer (or a consultant hired by the DOT) draws up the project plans and estimates the project cost. Along with design, the pre-bidding phase typically includes environmental review and right-of-way permitting/coordination.

Bid Letting: Once the plan of work is approved, a call for bids is posted. The DOT has discretion over when and where to post the call for bids, and over any bidder outreach efforts. The bid letting should include the detailed project plans and the engineer's estimate from the planning (pre-bidding)

[24] Vehicle miles captures the scope of the road network and total usage, so we think of it as a useful proxy for the demand for resurfacing. This normalization allows us to compare spending across states.

[25] For most other states, our raw data is not as comprehensive and we are not confident that they cover the universe of DOT projects. One exception is Texas, but we are missing a measure of project completion year for over half of the projects, limiting our ability to compare it to the FHWA totals.

[26] We believe the small differences in the total is partially due to some imprecision in how we assign project costs across years. With our data, all costs for a project will be attributed to a single year, even if some spending occurred outside of that year. With the FHWA data, the state reports totals by spending year, not project completion year.

stage. It will always include an itemized list of the quantity of each item needed to complete the project. Depending on the state, bidders may have to have completed a pre-qualification process, and they may have to pay a small fee in order to receive access to the project plans.

Submitting Bids and Project Award: Each interested contractor prepares and submits the bid to the DOT. All contracts for resurfacing projects are awarded via a unit bidding process, where the contractors total bid is the aggregation of their bid on each component of the project (Appendix Figure A.1). The lowest bid wins, unless the DOT determines there is a reason to exclude a bid (due to a bid being infeasibly low, for example).

Construction/Project Delivery: Once the contract is awarded, the DOT and the contractor determine the work start date. The contractor then performs the construction, though they may subcontract parts of the project to other private firms (see Section 5.2 for more details on subcontracting). The DOT inspects the contractor's work, coordinates permitting and road closure, and negotiates changes to the scope of the work as needed through a process known as "change orders".[27]

3.2 The Procurement Survey

We follow the general framework of the World Bank Doing Business "Contracting with the Government" survey, which collected data on the procurement laws and practices of 187 countries (Bosio et al., 2022). In the Doing Business project, each survey respondent is given a case study, which is an example road resurfacing project. They are then asked questions about the rules and practices that would dictate the procurement process of the project. Our case study and a description of the survey follows.[28]

3.2.1 Case Study

The case study describes a standard project contracted by a state DOT. The project entails resurfacing 5 miles of a flat two-lane road that is part of the National Highway System (but is not an Interstate). The road would extend from the outskirts of a medium sized city into the surrounding rural area, with an asphalt overlay of 1 inch. The estimated value of the contract is between $1 to $5 million.[29]

We choose to focus on resurfacing because it is both the largest category of state highway spending and the most easily comparable across states. Although highway building projects can be more

[27] Initial contract agreements specify precise plans and prices for each unit good that goes into a highway construction project. In the event of inaccurate plans or other reasons for change of project scope, either party can initiate a legal process known as a change order to alter the terms of the contract to reflect current conditions.

[28] The full survey is found in the Appendix.

[29] See, as an example, the project from our data that we discuss in Appendix B.

complicated and involve more discretion (which would be interesting from a procurement perspective), many states are not building new highways. In fact, between 2004 and 2014 the rehabilitation of roads increased from 47% to 72% of total capital outlays on state and local highway spending.[30]

Two consequences flow from this choice of case study. The first is that we are able to largely abstract away from issues of litigation and "citizen voice" because—though there may be competition to receive resurfacing dollars—resurfacing projects rarely arouse organized opposition (Brooks and Liscow, 2023). This allows us to focus on procurement and project delivery. The second is that our results have a greater chance of external validity because, however challenging procurement is for resurfacing, it is likely even more challenging for more complicated projects.[31,32]

3.2.2 Survey Questions

The survey questions are organized roughly chronologically over the course of a typical project. They ask about a variety of features of the procurement and construction processes, all which have the potential to affect costs. Specifically, the questions we ask can be grouped into five broad sets of hypotheses: (1) Transparency: Questions on the public availability of documents and details of past contracts all concern transparency. (2) Competition: Questions on outreach, advertising, and the number of bidders are intended to collect information on competition. (3) Quality: Questions on the bidder pre-qualification and bid screening focus on controls for quality in the procurement process. (4) Capacity: Questions on renegotiation, changes in the project details, paperwork and payments all concern the capacity of the agency and the bureaucratic or administrative process. (5) Corruption: Questions about bidder collusion, unethical contractor behavior, and improper state employee behavior concern corruption.

We depart from the World Bank survey by asking free form questions about what the procurement officials and bidders think drives costs and asking directly about the capacity of the state DOT and the competitive environment for the bidders. We provide more details about the procurement process in the U.S. and the literature related to the above hypotheses in Appendix A.

[30] Road expansion and new construction fell from 53% to 28% of outlays.

[31] One might wonder about the extent to which survey participants actually consider the case study, versus other types of projects, when answering questions. We are able to gain insight into this by comparing answers to two of our questions (Question 16 and Question 17 in Appendix I.), which are essentially identical, except that one asks about the case study, while the other asks about a more complicated design-build project. We asked about the number of change orders, and, for the case study question, the mean response was 3.80, while the design-build question, the mean response was 4.39. The fact that respondents expected more change orders on the more complicated project is suggestive evidence that respondents were attentive to the nature of the case study.

[32] When the Senate requested that the GAO produce a report on cost drivers in transit projects the first cost driver they suggested was "contracting and procurement."

3.2.3 Distribution

The surveys for the procurement officers and for the road builders and engineers (also known as contractors) are slightly different. This is sometimes as simple as question phrasing. For the contractor we ask, "To the best of your knowledge, how often does the agency do outreach to increase the bidder pool for highway construction projects?" To the procurement officer, who should know about the universe of projects, we simply ask, "How often does the agency do outreach to increase the bidder pool for highway construction projects?" There are also questions that are group-specific. For example, we only ask the contractors about their expectations of the level of competition. Therefore, we launch the survey separately for procurement officers and for contractors. The sample and survey distribution method for each group is described below.

We collect contact emails for procurement officers from two sources: the state DOT websites and the American Association of State Highway and Transportation Officials (AASHTO), a trade association for DOT procurement officials.[33] We directly email the survey to these contact emails. Respondents follow a link to complete the survey via Qualtrics.[34] We also collect contact emails for the contractors (road builders and engineers) from contractor trade associations and each state's public DOT website. Here we use public announcements of winning bidders or lists of pre-qualified firms.[35] As with the procurement officers, we email the contractors directly.[36]

Appendix Figure E.2 shows the geographic distribution of survey respondents. We have 123 survey responses from procurement officials in 50 states plus the District of Columbia.[37] We summarize the survey responses at the state level, averaging responses within each state. On average, we have 2.5 responses per state, though this ranges from 7 responses in Utah, to only one response in 12 states. On the contractor side, we have 211 survey responses from 47 "primary" states.[38] The firms we survey often operate in many states, but we ask them to consider their primary state of operation

[33]Specifically, we use the contact lists for AASHTO's Maintenance, Construction, Design, Materials, and Planning committees.

[34]Survey distribution started on April 19, 2022, and ended on September 1, 2022.

[35]The contact information sometimes includes only the firm name and phone number, so we then use google to find the firm's email address.

[36]Survey distribution started on June 9th, 2022, and ended on October 27, 2022.

[37]Given the number of DOT employees we contacted, this translates to a response rate of about 13.5%. Our goal was to collect at least one response from each state. Ten procurement official respondents were not original email targets, and thus are not included in the response rate. Of these, nine respondents received our survey through original email targets sharing the survey. One respondent used an advertisement that we posted on LinkedIn.

[38]This translates to a response rate of about 3%. Again, our goal was to collect at least one response from each state. We cold-email firms, and had no official government endorsement, and expected lower response rates than a phone or face-to-face survey. The response rate is comparable to the World Bank Enterprise Survey in New Zealand in 2023 (4.6%; see `https://microdata.worldbank.org/index.php/catalog/6459`), and the Federal Reserve's Survey of the Economic Well-Being of Households in 2022 (3.5%; see`https://www.federalreserve.gov/publications/2023-economic-well-being-of-us-households-in-2022-description.htm`).

while answering the survey. On average we have 4.5 responses per state, ranging from 20 responses in Texas, to only one response in 8 states.

4 Survey Descriptives

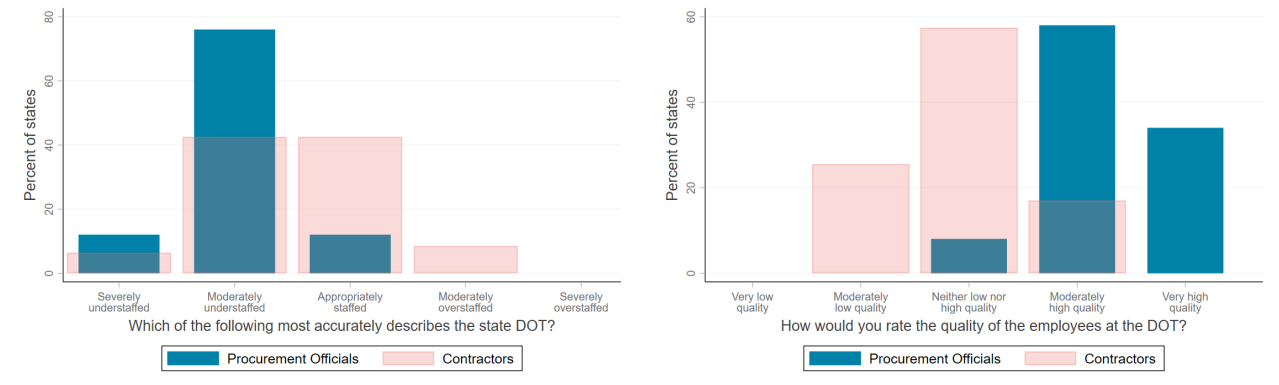
In this section we review some findings from the survey on the procurement process: where states agree, where there is substantial variation, and what respondents think drives costs.

4.1 Consensus Across States

Figure 2 shows that procurement officials agree on a few key issues. First, they are understaffed. Almost 90% of respondents answered that their state DOT was severely (20%) or moderately (68%) understaffed. Figure 2(a) shows this summarized at the state level. Second, employee quality is relatively high. About 30% of the respondents rated the quality of the employees at the DOT as "very high," 51% at "moderately high," and 20% at "neither low nor high" (Figure 2(b)). Contractors, like procurement officials, are considerably more likely to think that state DOTs are understaffed than overstaffed—though, on average, they do not feel as strongly. They also feel less positive about employee quality—most think that employees are of neither high nor low quality.

Contractors and procurement officials are aligned on their view of consultants, as Figure 3(a) suggests some consensus that using consultants increases costs at least moderately. We elaborate this further in Section 4.3, where we discuss cost drivers. The two groups also agree that corruption is not a problem—almost 80% of procurement officials and 60% of contractors responded "very small" to "How large of a problem would you rate corruption?" (Appendix Figure E.3).

Figure 2: DOT Employee Quantity and Quality

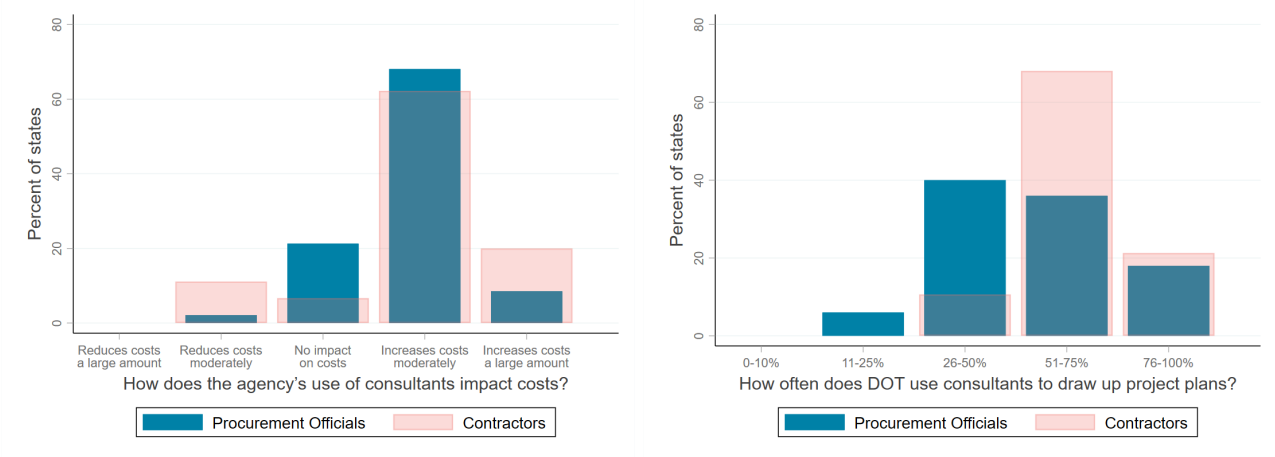


(a) Staffing Levels

(b) Employee Quality

Notes: Author survey: survey question on x-axis and frequency of response on y-axis. Data aggregated to the state level. Survey available in Appendix I.

Figure 3: Consultants



(a) Costs

(b) Usage

Notes: Author survey: survey question on x-axis and frequency of response on y-axis. Data aggregated to the state level. Survey available in Appendix I.

4.2 Variation Between States

We also find significant variation across states in a few key topics. For example, states differ in both the methods they use to estimate the cost of the contract and the information they share with bidders. While most states use similar projects from previous years and standardized unit cost analysis to estimate contract costs, a few apply more advanced techniques, such as project-specific technical drawings, market analysis, and risk estimation (Appendix Figure E.1(a)). Moreover, after developing the project plans and cost estimates, there is variation in how much information is shared with bidders (Appendix Figure E.1(b)). Previous research has shown that while providing more information to bidders can reduce costs by decreasing uncertainty and allowing them to make more accurate bids (De Silva et al., 2008), providing too much information on the competition (e.g. providing information on the number and identity of bidders) can increase costs, as contractors will be able to submit higher bids when they know there is less competition for the contract (Barrus and Scott, 2020). The largest difference between the response of the contractors and the procurement officials is in whether the state publishes the identity of bidders. We find that contractors who expect to face fewer bidders in an auction are more likely to know all of their competitors (Appendix Figure E.7(b)), irrespective of the information shared by the DOT.

Another source of variation is the use of consultants. Figure 3(b) shows that there is considerable variation in how often the DOT uses consultants to draw up project plans. Even though most respondents agree that using consultants can increase costs (shown in panel (a)), a state DOT may

not have the capacity to do all the required work in-house. In free responses, both contractors and procurement officials cite retirements and departures of high-quality state DOT employees as reasons for increased use of consultants.

We provide more details on variation across states in the Appendix. Appendix Figure E.5 shows the variation in timing in different steps of the procurement process, and Appendix I reports the sample means and standard deviations of each survey response.

4.3 Reported Cost Drivers

We start with a textual analysis of responses to the free response question, "What do you think are the main aspects of the procurement and administrative process of highway construction that increase construction costs?" This is the first question asked in the survey, so it allows us to understand what is front of mind for the procurement officials and contractors that responded to the survey before they are primed by the specific questions we ask them about procurement processes.

Appendix Figure E.9 displays a word cloud of the most frequent bigrams, with relative font size representing relative frequency. We then classify the bigrams by categories, using the most frequently cited bigrams to create the five categories.[39] Table 2 shows that competition is the most cited cost driver. Procurement officials mention competition explicitly when asked to describe cost drivers in their states. Consider these three quotes from the free response:

- "A main aspect that increases construction costs in [state] is competition. The timing of project lettings, the number of projects advertised on lettings, and the availability/workloads of contractors all factor into the competition. Increasing the number of bidders reduces procurement costs."

- "Competition: Costs tend to rise when the number of bidders falls (e.g., a single bidder can try to name their price). Number of bidders tends to fall as the market reaches capacity."

- "Limited funds cause limited projects cause limited contractors cause limited competition. Years of limited work has caused many contractors to get out of the business. Now we have very few contractors. Limited competition causes higher prices."

Despite the focus on competition and contractor availability in the free response, 70% of states *rarely* do bidder outreach (Appendix Figure E.4). This could be because the DOT has low capacity or

[39] See Appendix Table E.2 for a list of key words used for each category. We are able to classify over 75% of bigrams in these 5 categories, after we remove the bigrams that only appear once. The categories are motivated by the terms that appear in the top 20 bigrams. The unclassified bigrams are usually more neutral phrases or nouns, such as "start date," "additional cost," "state dot," "contractor work."

Table 2: Free Response on Cost Drivers

Category	N	%
Competition	434	18.66
Materials and Labor	417	17.93
Project Plans and Scope	388	16.68
Bureaucracy and Red Tape	324	13.93
Risk and Complexity	222	9.55

Notes: Author survey. Respondents are asked the following free-response question: "What do you think are the main aspects of the procurement and administrative process of highway construction that increase construction costs?" This table displays the relative frequency of various categories of bigrams (two words used together). We perform basic text cleaning on the original responses and identify bigrams, following Liscow and Pershing (2022).

willingness to do outreach, or because they know the market well and no other capable firms exist in the area.

The survey responses of the contractors also show how a lack of competition can have immediate implications for costs.[40] Appendix Figure E.7 verifies that in states where competition is mentioned as a concern, contractors report expecting to face fewer competitors. Moreover, the fewer competitors a contractor expects to face, the higher the probability they know all of their competitors, and thus are likely have some information about competitor's capacity and costs. Only 5.7% of contractors report that there are often firms bidding that they do not expect (Appendix Table E.1).

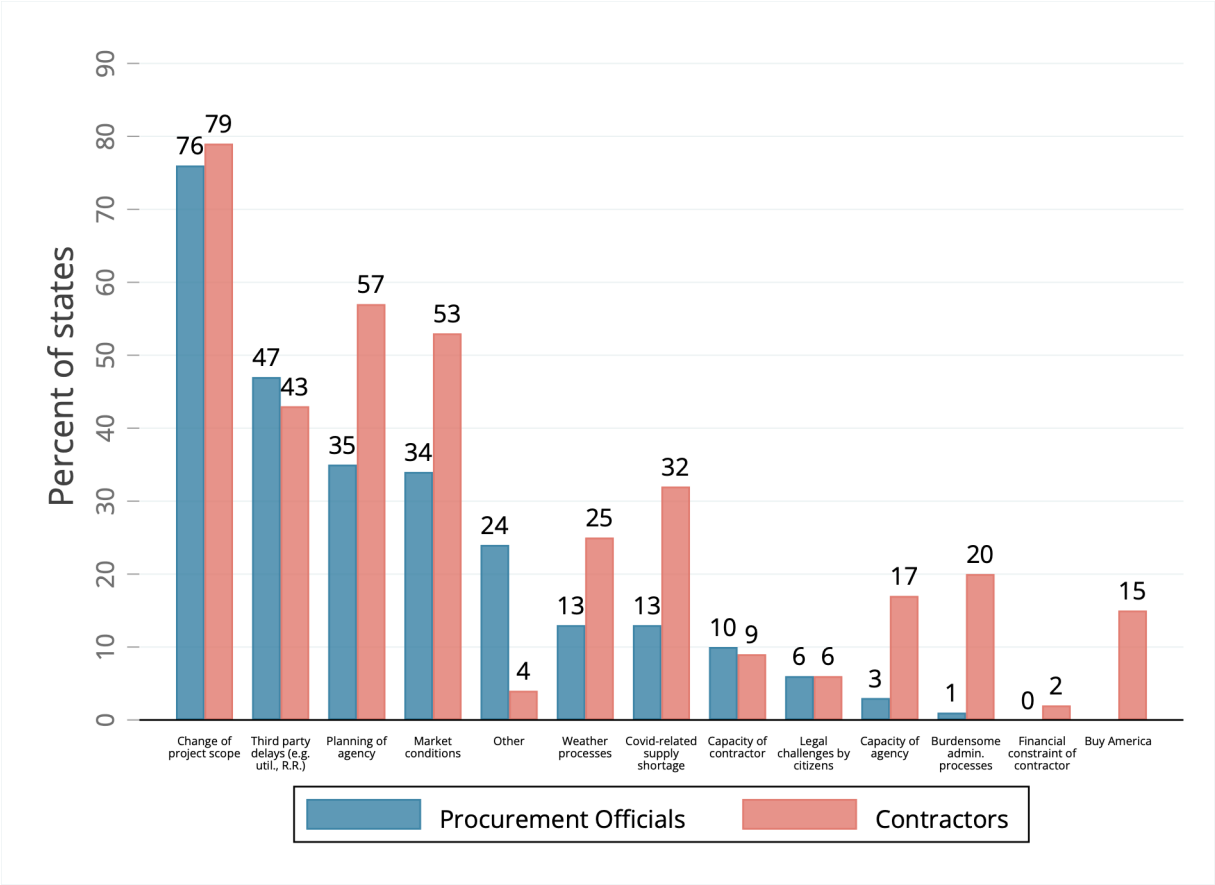
The next most commonly cited cost driver is Materials and Labor. We can control for differences in local labor costs using wages in the highway construction industry (Table 1 Column (2)), and we do not find that it explains much of the variation across states.[41] The next two categories the respondents identify as cost drivers are related to capacity. Phrases such as "Bid document," "poor plan," "plan spec," "change order," and "plan error" suggest inadequate bidding plans, a potential result of limited DOT capacity. For example, one DOT employee writes, "Bad or unclear specifications or contracts breed uncertainty, which contractors will factor into their prices as risk." These type of cost drivers are mentioned in 16.7% of bigrams in the free response, which we call "Project Plans and Scope." Further, phrases such as "certify payroll," "requirement federal," "paperwork require," and "red tape" are categorized as "Bureaucracy and red tape," which make up 13.9% of responses.

Figure 4 summarizes what procurement officials and contractors think drives cost *overruns*. Here respondents are given a list and are free to choose as many items as they want. The question is a bit more specific than the free response question on cost drivers, because of the focus on overrun (i.e. ex

[40] We note that contractors also mention competition as a cost driver, but they focus on competition in the downstream market for subcontractors. We discuss this further in Section 5.2.

[41] We do not have input prices at the state level, but note that increases in the price of materials did not contribute to the increase in road building costs over time (Brooks and Liscow, 2023). We note that the cost of labor and materials, partly due to federal and state requirements (i.e. Davis-Bacon and Buy America) can increase costs across the country, but are unlikely to materialize as variation in costs across states.

Figure 4: Reasons for Cost Overruns



Notes: Author survey. Respondents are asked "If a project has a cost overrun, what are usually the main reasons? Select all that apply." Data aggregated to the state level. Survey available in the Appendix. Only contractors were given the option to choose "Buy America."

post increases in the cost). Higher costs due to materials, labor, and competition are more likely to be realized at the bidding stage, and come in the form of higher bids. Consistent with Table 2, the most common cause of cost overruns cited by both procurement officials and contractors was "change of project scope." The second most highly cited cost driver, from the perspective of the contractors, was "planning of the agency." Changes in project scope are directly downstream of poor planning.

In the previous section we briefly highlighted the finding on costs and consultants (Figure 3(a)). Respondents are given the opportunity in the survey to elaborate on the role of consultants, and generally highlight issues with misaligned incentives, lack of institutional knowledge, and timing. One contractor explains that: "3rd party consultants are highly compensated based on a cost + factor, they don't have enough skin in the game during construction," while another simply summarizes the issue as: "The ability to make decisions in the field does not exist with most consultants."[42]

[42]In more detail, another respondent says "Third party consultants are paid by the hour for all work plus a multiplier. They are not incentivized to complete a project, there are delays in communication and the third party consultant will deny a potential change order request until it becomes a claim for adjustment. They typically do not work to resolve

Lastly, we ask respondents whether there are labor or subcontracting requirements that increase costs. The responses are tabulated in Appendix Figure E.6. There is widespread consensus for the role of subcontracting requirements in driving costs, which we view as related to the concerns about competition in the prime contractor market.[43]

4.4 Nationwide Trends

This narrative from the survey suggests that DOT capacity and costs are closely related. A lack of capacity at the DOT can hurt the quality of project plans, either from under-staffing in-house or from outsourcing to consultants with limited institutional knowledge and misaligned incentives (GAO, 2008). The lack of specificity in plans introduces risk to the contractor which increases contractor bids and opens up the DOT to a costly and time-consuming renegotiation process when the scope of project changes.

We use administrative data on public sector employment to investigate capacity issues in state DOTs. We see that state DOT employment has experienced a substantial decline in the last 20 years. Between 1997 and 2020 full-time employment in state "Highways" (as defined by the Census Annual Survey of Public Sector Employment and Payroll) has shrunk by 40,000, a decrease of about 20%. Total state public sector employment rose over the same period, such that the "Highways" share of total state public employment shrunk from over 6% to about 4.5% (Figure 5(a)). The census data is consistent with the survey evidence: states that experienced the largest losses in employment are most likely to report being understaffed.[44]

The descriptives from the survey also highlight the role of competition as a cost driver. We use administrative data on industry structure to study the competitive landscape. We observe a change in the market structure in the highway construction industry over the last 10 years, with most states losing establishments. Almost 70% of states experienced a decrease in establishments in the Highway Construction industry over the period of 2007-2017 (Appendix Figure F.1), with the median state experiencing a decrease of 13% in total industry establishments.[45]

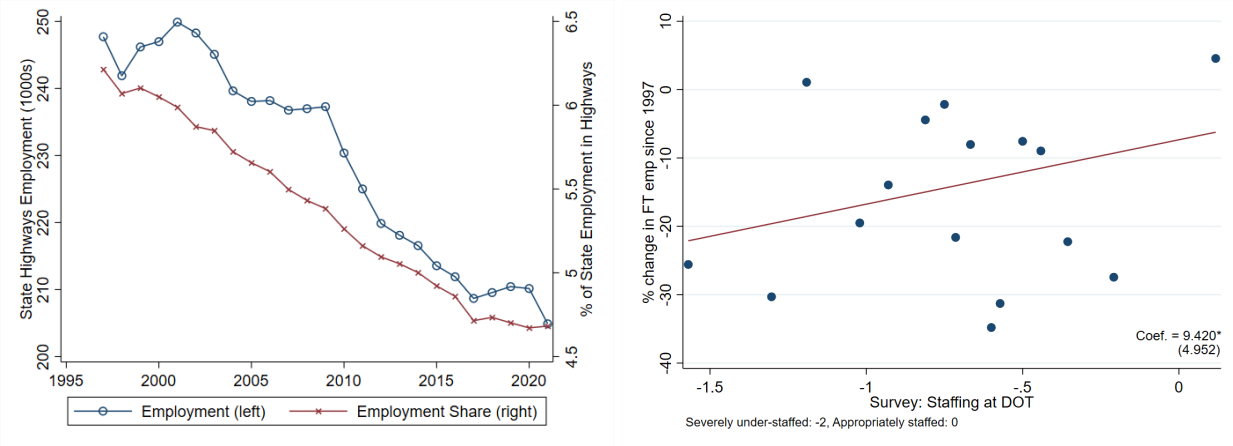
issues in the field." There were more egregious complaints about consultants as well, for example: "The third party companies aren't trained and usually don't have a clue." However, not all the responses were negative, especially when they were discussing contractors used in the design phase. Here, one contractor replied that "consultants sometime do a better job on the design and planning," while a procurement official mentioned that this might be due to an abundance of caution ("One issue is that consultants can only design with 100% confidence of no failure. They must err on side of caution for every design").

[43]Subcontracting requirements take the form of limits in the share of work that can be subcontracted, as well as federal or state requirements on the composition of those contractors.

[44]Census's definition of "Highways:" Activities associated with the maintenance and operation of streets, roads, sidewalks, bridges, tunnels, toll roads, and ferries are included at this function. Snow and ice removal, street lighting, and highway and traffic engineering activities are also included here.

[45]A 13% decrease translates to a loss of 17 establishments in the median state.

Figure 5: State Highway Employment



(a) Time Series (b) Survey

Notes: The panel on the left shows the total state employment in the "Highway" category, both in levels and as a share of public sector employment (US Census Bureau, 1997-2021). The panel on the right correlates the state specific "highway" employment change with state-level concerns about staffing, as measured by the author survey. The state-level "highway" employment change is measured from 1997 to 2021, but the figure looks similar using a shorter time span for the difference.

In summary, the survey respondents are highly concerned with two inputs to the procurement process: DOT capacity and competition between contractors. We see these two themes highlighted in many different survey responses, and we use external data to verify that both DOT capacity, as measured by employment, and competition, as measured by construction establishments, have declined in the recent past. We also have suggestive evidence that these two cost drivers are connected. States with higher quality DOT employees are also more likely to do bidder outreach, and have slightly higher levels of bidders (Appendix Figure E.8). In the next section we will link the potential cost drivers we highlight above, and other procurement practices that we record with the survey, to our new data on realized infrastructure costs.

5 Correlations: Procurement and Realized Costs

After accounting for state and project observable characteristics in Table 1, substantial variation in project-level costs remains across states (see Appendix Figure D.5). We now look to see how much of this remaining variation is explained by the differences in procurement practices across states.

We start with two variables that capture some of the most cited cost drivers from the survey: DOT capacity and competition. For DOT capacity, we take the number of full-time employees in state highways (from the Annual Survey of Public Sector Employment and Payroll) and divide it by the population of that state, in thousands (from Census population estimates). Columns (1) and (2)

Table 3: Project Costs and Hypothesized Cost Drivers

	Project-Level Log(Cost/Mile)			(Cost - Estimate) / Estimate	
	(1)	(2)	(3)	(4)	(5)
Hwy Employment per Capita (1,000)	-0.263+	-0.263+	0.022		0.046
	(0.164)	(0.165)	(0.113)		(0.095)
Number of Bidders		-0.011	-0.083**	-0.050**	-0.051**
		(0.044)	(0.035)	(0.021)	(0.019)
Engineer's Estimate (Log(Cost/Mile))			0.838***		
			(0.158)		
Observations	250	250	94	94	94
R-squared	0.37	0.37	0.68	0.11	0.12

Notes: All columns use the regression specification from Column (2) of Table 1. Columns (1), (2), and (3) incrementally add hypothesized cost drivers as regressors. Columns (4) and (5) use the deviation from the engineer's estimate as the dependent variable. The dependent variable is winsorized so that the top value is 1, i.e. costs are double the engineers estimate. This affects 3 observations. Highway employment per 1,000 people is calculated from Census ASPEP and Census state population data. The number of bidders is gathered by the authors from project documents. The authors were able to find an engineer's estimate for 94 of the 250 projects in the sample. ***p < 0.01, **p < 0.05, *p < 0.1, +p < 0.15.

show that an increase of one DOT employee per thousand people is associated with a 26% decrease in project costs (p-value = 0.12).[46] For the mean project in our sample, this is a reduction of about $85,000 per mile at the mean.

For competition we use the number of bidders, which is a project-level variable that we collected directly from the state. The relationship between competition and costs is much weaker at the baseline. Once we control for the "Engineer's Estimate," and therefore also the unobservables that affect bidder participation, we see a strong negative correlation between the number of bidders and costs, as expected (Column (3)).[47] One additional bidder is associated with 8% lower costs per mile, or a savings of $30,000 per lane-mile.

In Columns (4) and (5) we measure the difference between realized cost and the engineer's estimate as our outcome of interest. Here, we can see that the difference between cost and estimated costs shrinks with the addition of a competitor: one additional bidder is associated with a 5% decrease in cost overrun, using the engineer's estimate as the baseline for costs instead of the winning bid. Increased competition is correlated with the DOT paying *less* than they estimated for a given project.

[46] The p-value on DOT capacity is 0.115 in Column (1) and 0.117 in Column (2).

[47] The "Engineer's estimate" is the DOT engineer's estimate of how much the project will cost. Unfortunately we only have data on the engineer's estimate for 19 states, which is why we do not use it more broadly across our analysis.

5.1 Survey Correlates

We now take the survey responses and correlate them with the project-level cost data. The dependent variable is log cost per mile, as in Table 1. We also control for all of the project, local, and weather observables that we included in Column (2) of Table 1, and cluster standard errors at the state level. The survey responses from the procurement officials and the contractors are aggregated to a state-level average, unless the question was only asked to one group. Each response variable is normalized to have a mean of zero and standard deviation of one, such that correlations are comparable across questions. In total, we estimate 79 correlations of survey responses with realized project costs.

Both procurement practices and infrastructure costs vary across states, as highlighted in Sections 2 and 4. However, we find that most state-level procurement practices do not correlate with realized costs: only 8 of the 79 survey responses that we correlate with costs are statistically significant at the 10% level (after adjusting for multiple hypothesis testing using the Romano-Wolf multiple hypothesis correction).[48] The correlations that do emerge are consistent with the two themes that predominated in the descriptive statistics: 1) limited state DOT capacity and 2) limited competition.

Figure 6 presents the significant correlations results by hypothesis and lists them by the absolute value of the magnitude. Results for all survey responses can be found in Appendix G, including the (often much smaller) unadjusted p-values.[49] We note that the survey responses have explanatory power. When we use the observable cost drivers, we can explain about 30% of the variation in costs between states and projects. When we add all of the survey variables, this increases to 60% (Table G.5). Therefore, adding the survey variables has the same effect, vis a vis explanatory power, as adding the Engineer's estimate to the regression (Table 3, Column (3)).

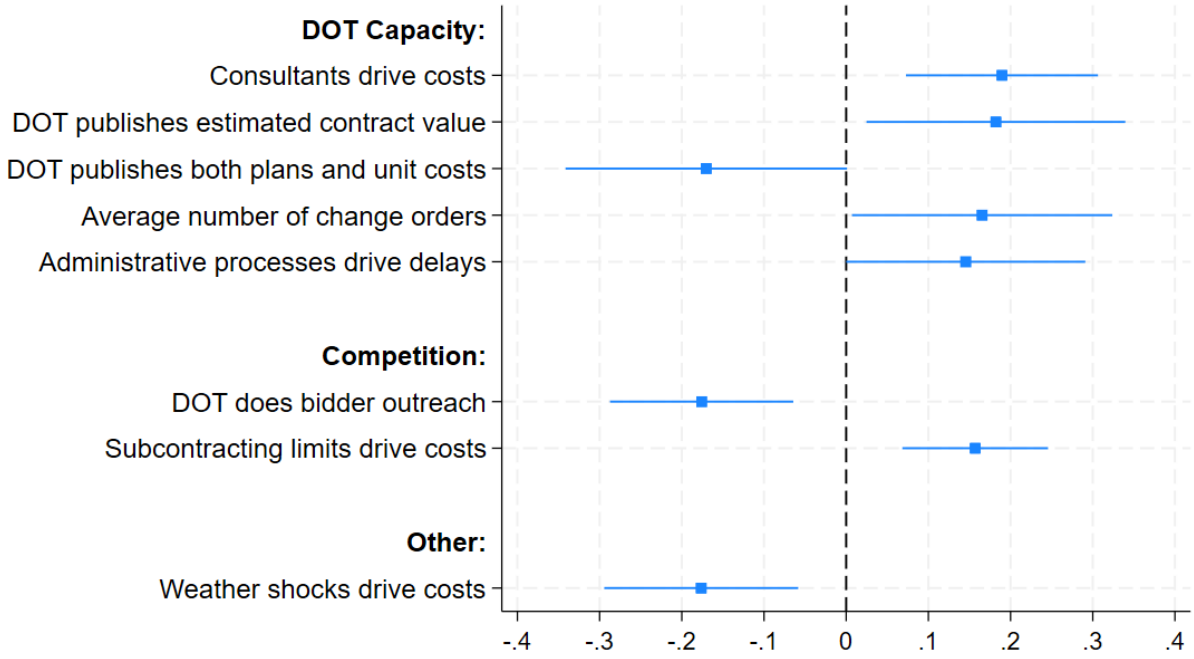
Capacity We turn first to the results concerning DOT capacity. As we discussed earlier, consultant use by state DOTs can be an indicator of limited in-house resources. If the state DOT is understaffed and lacks the personnel necessary to complete a project, then it is likely to outsource work to consultants.[50] In fact, we find that states where respondents cite consultants as a cost driver do have

[48] The Romano-Wolf multiple hypothesis correction is typically used when testing a large number of statistical hypotheses. As we test more hypotheses, the probability of falsely rejecting a true null hypothesis increases. The Romano-Wolf multiple hypothesis correction addresses this problem by controlling for the "probability of rejecting at least one true null hypothesis among the family of hypotheses under test" (Clarke et al., 2020). We consider all of our survey results listed in Appendix G to be in the same "family of hypotheses". For more information on the Romano-Wolf correction, see Romano and Wolf (2005a,b), Romano and Wolf (2016), Clarke et al. (2020).

[49] When we consider the unadjusted p-values we find that 12 of the survey responses are significant at the 10% level, instead of 8. Most are closely related to the variables we will discuss before (i.e. 'Selected "Planning on the Agency Side" as a cost driver', and 'number of change orders for design build contracts' are significant under this more relaxed measure).

[50] See, for example, the report by the Government Accountability Office (GAO) on outsourcing by state DOTs for federal-aid highways (GAO, 2008). They find that lack of in-house staffing is the most common reason for hiring a

Figure 6: Survey Correlates: Significant Results



Notes: This figure shows the correlation coefficients between the survey responses and the project cost that are significant at the 10% level, or close to significant at the 10% level, after adjusting for multiple hypothesis testing using the Romano-Wolf multiple hypothesis correction (Clarke et al., 2020; Romano and Wolf, 2005a,b, 2016). The dependent variable is log cost per lane-mile. Regressions include controls for project, local, and weather observables (per Column (2) of Table 1), and cluster standard errors at the state level. The survey responses from the procurement officials and the contractors are aggregated to a state-level average, unless the question was only asked to one group. The bars represent the 90% confidence interval, which is determined using Romano-Wolf adjusted p-values. Each response variable is normalized to have a mean of zero and standard deviation of one, such that correlations are comparable across questions.

significantly higher costs. Note here that we can only measure the cost of the project that is paid to the contractor, not any internal staffing costs for the DOT. Therefore, the increase in costs due to the consultant is not because the consultants bill at a high hourly rate (which can also be true). There are a few mechanisms that can lead contractors to increase costs ex-post. The most frequently cited by industry professionals is a lack of institutional knowledge, which can lead to both mistakes in the project plans and delays when communicating with contractors.

For this question, survey respondents were asked, "How does the agency's use of consultants impact costs?" Respondents could choose from five different answers, ranging from "Reduces costs a large amount" to "Increases costs a large amount." Interestingly, this correlation displays the largest magnitude of our statistically significant results, indicating that consultants could be one of the key

consultant. Further, the report cites retirements as a driving factor for the lack of in-house expertise, which we will explore later in this section. Specifically, the report writes: "Erosion of state DOTs' in-house expertise as a result of staff cuts and retirements also creates additional risk in the long term and creates challenges for state DOTs in effectively overseeing consultant and contractor work" (p.35 GAO, 2008).

mechanisms through which weak state DOT capacity could increase costs. A one standard deviation increase in reported consultant costs is associated with a 19% increase in cost per lane-mile. At the mean, this corresponds to a $70,000 increase in cost per lane-mile.

The next two correlations highlight the information that the DOT provides to bidders. Here, we find that when the DOT publishes the estimated contract value, costs are higher. There may be two reasons for this. First, it is possible that the state systematically overestimates costs and anchors bidders to an inflated price. Second, publishing the total estimated cost provides some information to the bidders, but is not as informative as providing estimates at the unit level (and some states do provide this more granular information to bidders). To probe this further, we create a measure of "Best Practices", which sums the selection of 'Project Plans' and 'Estimated Standard Unit Costs', and subtracts the selections of the less informative 'Estimated contract value' as well as information that would allow contractors to learn more about potential competition and make less competitive bids when needed ('Number of bidders', 'Identity of bidders', and 'Bid Bond'). This measure of "Best Practices", which is labeled "DOT publishes both plans and unit costs" in Figure 6, is negatively correlated with costs: a one standard deviation increase in the "Best Practices" score is associated with a 17% decrease in cost per lane-mile.

Next, we see that change orders have a positive correlation with costs—the more change orders that are expected, the higher the costs. Frequent change orders directly lead to higher costs through delays and costly renegotiation; they are also a downstream symptom of poor administrative capacity at a state DOT—many contractors reference poor-quality project plans made by third-party consultants as a cost driver (Table 2 and Figure 4). One additional change order is associated with a $25,000 increase in cost per lane-mile, at the mean.

Lastly, we find that states that are more likely to flag "burdensome administrative processes" as a source of project delays have higher realized costs. It seems likely that slow administrative processes could be a result of limited DOT capacity. If a state DOT is understaffed, each staffer will have a large workload, likely leading to delays as the staffers work through administrative hurdles. A one standard deviation increase in the proportion of people that cite administrative processes as a source of delays is associated with a 14% increase in cost per lane-mile.[51]

Most of our significant results related to DOT capacity speak to potential symptoms of understaffing. It is worth noting that we have suggestive evidence on a different axis of DOT capacity—quality of DOT employees. In the survey, we ask, "How would you rate the quality of the employees

[51]This survey response explicitly links burdensome administrative processes with delays. We note that burdensome administrative processes can also increase costs if it prevents entry.

at the state department of transportation?" A higher DOT quality is associated with lower costs, though this correlation is not statistically significant at the 10% level after adjusting for multiple hypothesis testing.[52] The magnitude is striking– a state with a neutral rating has 28.6% higher costs than one that rates the DOT employees as "moderately high quality," all else equal. This corresponds to a $105,000 increase in cost per lane-mile.

Competition The next two significant correlations concern competition. First, states that do outreach to increase the bidder pool have significantly lower costs, highlighting both the importance of competition and the role the DOT can play to increase it.[53] A one standard deviation (12 percentage point) increase in bidder outreach is correlated with a 17.6% decrease in costs. At the mean, this translates to a decrease in costs of $65,000 per lane-mile and $1 million at the project level. This is striking, given the relatively low levels of bidder outreach we see across states (Appendix Figure E.4).

There is also a relationship between subcontracting restrictions and realized costs. Many contractors do not have the capacity to do 100% of the work of resurfacing a highway in-house, so they subcontract parts of the project.[54] State governments can restrict the share of a contract's dollar value that prime contractors (those that bid on the project) are allowed to subcontract, and states can vary in how simple it is to add subcontractors to a project.[55] A one standard deviation increase in citing issues with subcontracting limits is associated with a 15.7% increase in costs. This is a large effect; in a state where every respondent selects "Limits on share of project that can be subcontracted" as a cost driver realized costs are 62% higher than in a state where none of the respondents select subcontracting limits, all else equal.[56]

Other Potential Cost Drivers The final statistically significant correlation regards weather. Selecting "Weather Shocks" as a source of cost overruns is *negatively* correlated with costs. The specific question is, "If a project has a cost overrun, what are usually the main reasons?" So, it may be that in states where the main reason for cost overrun is weather, things are operating well.

[52]The unadjusted p-value on the employee quality rating is 0.09 while the Romano-Wolf p-value is 0.21; see Appendix G.

[53]This has also been found to be important to procurement in the Government Performance Lab's work in St. Paul, Minnesota (Government Performance Lab, 2016; Liebman and Azemati, 2016).

[54]For example, a contractor may be able to produce asphalt in-house, but may have to hire another firm to put down concrete for a curb cut. In most states the bidding contractor does not need to submit the list of subcontractors at the time of bidding, but they do need to estimate the costs of the subcontracted work.

[55]All projects that receive federal funding have an upper bound for subcontracting of 70% of contract value

[56]Generally, subcontracting limits may be either lower or upper bounds—in the case of DBE regulations, there is sometimes a lower bound on how much of a contract's value must be let out to a DBE-qualified subcontractor. The relationship between subcontracting limits and costs does not seem to come from DBE-related lower bounds: states that cite DBE requirements as a cost driver do not seem to have higher realized costs.

Appendix Tables G.1-G.4 presents the results of all of the correlations with cost, which includes the beta estimates, unadjusted p-values, and the Romano-Wolf p-values. We note that not every capacity or competition survey question has a significant correlation with costs—but it is striking that none of the other original hypotheses exhibit any significant correlations. In Section 3.2.2 we introduced five broad hypotheses related to procurement costs: transparency, competition, quality, capacity, and corruption. We find no relationship between realized costs and questions on transparency, quality, or corruption.[57]

On corruption, we asked questions related to general corruption, bidder collusion, unethical contractor behavior, or improper state employee behavior. Very few respondents cited concerns with corruption, and these concerns did not correlate with realized costs (Appendix Table G.4). However, we had fewer respondents for these questions and were concerned that this could be driving the null results. We were also concerned that perceptions of corruption among survey respondents might differ substantially from relative levels of corruption in reality. Thus, we also tested for corruption using an external measure—a state-level corruption index from Boylan and Long (2003), constructed using surveys of State House reporters. Similar to our survey questions, the Boylan and Long index showed no correlation with project costs.

In Appendix Table G.2 we see that the average length of time between procurement steps at the state level does not correlate with realized costs, which goes against common wisdom on the cost of delays. However, we note that costs and project duration exhibit a tight positive relationship. We have information on duration in 33 states. Appendix Figure D.6 shows that a standard deviation increase in duration (50 days per mile) correlates with 43% higher costs per mile. This is consistent with the discussion of the role of delays in Section A.4.

5.2 Additional Evidence: Subcontracting and Administrative Burden

Subcontracting Requirements We investigate the role of subcontractors, given the finding that states where subcontracting limits are cited as a cost driver have significantly higher costs. Procurement officials and contractors in over 80% of states mentioned the Disadvantaged Business Enterprise (DBE) program as a cost driver (Appendix Figure E.6). However, we do not find any correlation

[57] On transparency, we asked questions related to the public availability of documents during bid letting, bid evaluation, and construction. This could include providing public information on past contracts, excluded bidders, and results of change orders. We do not find any correlation between these indicators of transparency and the project costs. On quality, we asked questions about bidder exclusion and bid evaluation. This includes a set of questions on how the DOT identifies and/or rejects unrealistically low bids or mathematically/materially unbalanced bids. None of these questions on bid evaluation correlate with costs. On exclusion, none of the questions on bidder pre-qualification correlate with costs.

between this response and realized costs. This may be due to lack of variation, as it is a federal program. This may also be due to the politicization of the program; some contractors and officials view it unfavorably as an affirmative action initiative. However, since we see a correlation between subcontracting limits and costs, we use the DBE program as a case study to further probe the role of competition in the subcontracting market. If states do not have a thick market of qualified firms, any DBE requirements may directly affect costs through limiting competition at the subcontractor level.

Here, we collect two variables to measure the market for Disadvantaged Business Enterprise (DBE) firms. First, at the project level, we assemble the project-specific "DBE goal" from the bid documents. This is the percentage of work that the DOT would like to be subcontracted to a DBE, which the state DOT can vary by project in order to meet overall state-wide goals. Second, we create a measure of the thickness of the DBE market by calculating the number of registered DBE firms (from public state DBE registries) over the number of construction establishments in the state (from Census).

Table 4 shows that projects with higher DBE goals cost more. The mean DBE goal is 4.7% and the standard deviation is 5.1%. A one percentage point increase in the DBE goal is associated with 2.5% higher costs, while a one standard deviation increase is associated with 13% higher costs per mile.[58] However, in states with a thicker DBE market costs are, weakly, lower. Of course, these are correlations, and projects with high DBE goals could differ from other in a host of ways that also increase costs. It may also be that states that are not able to encourage entry of DBE firms are high cost in other ways. Still, it remains an additional piece of evidence for the role of competition as a cost driver.

Administrative Burden Next, we study the relationship between cost and the length of the documents that bidders need to submit to compete for the project. This is a proxy of administrative burden at the DOT, as we find evidence from the survey that administrative processes drive delays, and therefore costs. These bid documents, or "packets," are required for a bid proposal and are published as templates for contractors to fill out. The packet includes the plans and details of the project, which is helpful information for the bidder, but also includes all of the compliance requirements and local, state, and federal regulations that apply to the project. The average length of such a packet in our sample is 164 pages, with a standard deviation of 80 pages.

We collect data on "bid packets" from various state DOT agencies, specifically related to state

[58] We are not able to collect this data for all states—we have DBE goal data in 32 states and DBE market data in 36 states. States that have already met their state and federal DBE thresholds will not post "DBE goals" at the project level, so we could instead code them as 0. The patterns remain unchanged. The DBE market data is collected directly from the publicly posted DBE registries.

Table 4: Subcontracting Requirements and Administrative Burden

	Project Cost per Mile (log($M))			
	(1)	(2)	(3)	(4)
Project DBE Goal (%)	0.022+		0.025*	
	(0.014)		(0.014)	
State DBE Share		-0.060	-0.254	
		(0.311)	(0.286)	
Bid Document Page Length				0.002*
				(0.001)
Observations	119	119	119	125
R-squared	0.49	0.47	0.49	0.50

Notes: The table presents a simple regression between resurfacing costs and measures of subcontracting requirements and administrative burden across states. The regressions include all of the controls from Column (2) of Table 1 (project details, local characteristics, state weather), as well as highway employment per capita to capture the role of state capacity that may be correlated with the DBE goal and/or bid document page length. Standard errors are clustered at the state level. The DBE goal is a project-level variable that measures the % of the project that needs to be completed by a DBE firm. This is collected from the bid letting. The DBE share is a state-level variable that measures the number of construction firms registered as a DBE, as a share of the total number of construction firms. This is collected by the authors by downloading DBE registries in each state that it is available (36 states). ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15.

highway resurfacing projects, and measure the page length of the PDFs.[59] We manually search online for publicly available templates and are able to successfully find PDFs for 25 states.

Table 4, Column (4), shows the results of the simple regression of state bid document length and realized project costs. The result implies that an increase of 10 pages is associated with a 2% increase in project costs per mile, while a one standard deviation in page length is assocated with a 16% increase in costs. We cannot rule out the possibility that some states tend to have more complex projects and thus a longer template, but our templates are for the whole state, not particular projects, and we control for project complexity, limiting these concerns. We view this correlation as further evidence that administrative inputs at the agency can drive costs. This may operate through delays and time cost to the DOT employees preparing and reviewing the compliance documents, or it may operate through competition, deterring potential bidders who do not have the experience in how to properly complete the packet (Hjort et al., 2020).

6 Evidence on State Capacity from Caltrans

We further investigate the role of capacity as a cost driver with detailed administrative data from Caltrans, the state of California's DOT. First, we quantify the relationship between *individual* engineer quality and the realized costs of standard DOT infrastructure projects. Second, we use panel variation in engineer retirements by district as a quasi-experimental capacity "shock," which we use

[59] See Appendix F.4 for more details on the data collection process.

to study aggregate effects.

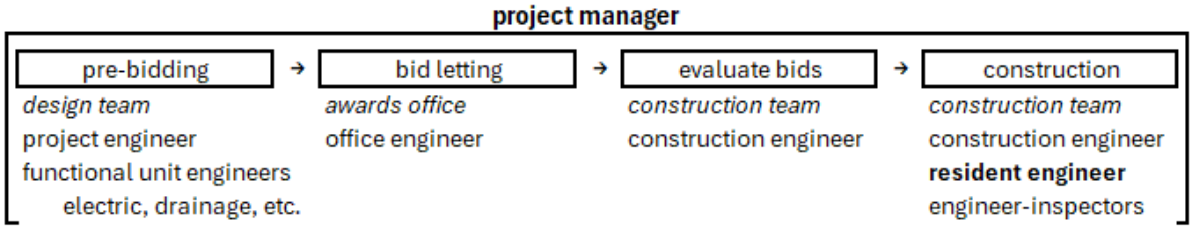
We focus on employee quality and retirements as our proxies for capacity because survey respondents emphasize these when asked about state DOT employees. As a first example, one procurement official detailed that "We have a lot of talented individuals who are in the later stages of their career. Our issue in [state] is attracting new talent, the current candidate pool is very weak." Another added that there was difficulty competing with the private sector: "Open vacancies, and experienced staff either retiring or moving on, makes it difficult to train new hires with no experience or just out of college. It takes time to get them on board to produce contract plans and getting them up to speed on our standards. We also have hurdles with offering enough compensation to compete with private engineering firms." Contractors also mentioned preferring more experienced engineers: "Older employees tend to listen to contractors on how a project could be constructed. Newer employees tend to do things 'by-the-book' as they are usually unfamiliar with what the plans & specs require."

The qualitative evidence on employee experience and quality, paired with the nationwide decline in DOT employment (Figure 5(a)), motivates our approach. We contribute to the literature on the role of the individual bureaucrat and the effect of increased employee workload on procurement outcomes (Best et al., 2023; Giuffrida and Raiteri, 2023; Warren, 2014). Our analysis is distinct in two important ways. First, our focus is on the procurement of infrastructure. Infrastructure procurement is generally much more complicated than the procurement of goods, which makes up most of the procurement data and research. In fact, our data allows us to differentially analyze the effect of engineer quality for two separate types of engineers involved in the project, which helps to isolate where and how individual quality can matter for costs. Second, in our study of retirements, we are not primarily interested in the shock of increased workload borne from a retirement. Instead, we take a more holistic view, considering the loss of experience that is induced by retirements.

6.1 Data

In California, the DOT (Caltrans) employs over 7,000 engineers across 12 geographic districts and the state headquarters. Each district is responsible for overseeing transportation projects in its jurisdiction. We have two sets of administrative data on projects that are delivered by Caltrans. The first is specifically on the construction phase of the project. This includes projects that were awarded between 2000 and 2023, and is complete with project characteristics (district, location, route, description, length), outcome variables (winning bid, project duration, and final cost), and the

Figure 7: Project Delivery at Caltrans



resident engineer that was assigned to the project.[60] The resident engineer is the employee on the ground who communicates with the contractor throughout the construction phase. The second set of data from Caltrans is on project delivery. This dataset spans 2011-2023 and includes information on budget and spending for other phases of the project (not only the construction phase). Importantly, this dataset includes the identity of the project manager. This is the employee that oversees the entire life cycle of the project, from planning to construction. The project-level data includes all types of highway infrastructure projects; we do not subset to only resurfacing projects. Lastly, we collect data on the salary and benefits of all Caltrans engineers in our project-level data, and the retirement year and pensions of retired engineers, between 2011 and 2023, from the nonprofit Transparent California, which itself obtained the data through FOIA requests.

6.2 What Do Caltrans Engineers Do?

We would like to quantify the effect of engineer quality, broadly defined, on realized costs, across the state of California. Before we discuss our approach in detail we provide some context on the engineer position at Caltrans.

The majority of engineers at Caltrans, and, therefore, in our data, have the title "Transportation Engineer (Civil)." In the project-level data, this is 83% of resident engineers and 23% of project managers. This job title encompasses many potential tasks, which we list in Appendix H. Engineers can hold this job title throughout their careers. Entry-level employees will begin assisting with plans, environmental reports, and resident engineer work. As they gain experience and qualifications, they will begin to produce the work themselves and may even oversee other employees and manage projects.

Multiple engineers and other personnel are involved in the delivery of a single Caltrans project. The project manager is generally a senior engineer who is responsible for overseeing the life cycle of the project, from planning to completion.[61] This includes the pre-bidding, bid letting, bid evaluation

[60] A subset of the construction data spans 1970-2023, but this file only includes project descriptions and resident engineers, not final costs.

[61] In our data, about 70% of project managers are at a senior engineer position (Appendix Table H.1).

and award, and construction phases of the projects. Figure 7 shows each phase of the project, the office or team that is associated with the phase, and the types of engineers involved. In bold, we highlight the engineers that we observe linked to the project data, this is the project manager (on the top) and the resident engineer (in construction). In the construction team, entry-level transportation engineers will start as inspector-engineers. Then, after taking a license exam, they will be promoted to a resident engineer, who is responsible for the contract administration and construction of the project. The construction engineer provides counsel for the resident engineers across many projects.

There is also a pre-planning and approval phase to project delivery which is not pictured in Figure 7. Environmental reports and communication with the public will be an important part of this pre-planning, and is included in the staff engineer job description.[62] For the senior engineers, communication with the public and developing reports can be an even larger part of the job.[63]

6.3 Engineer "Quality" and Project-Level Costs

We start by quantifying the role of individual engineers on project-level outcomes. We depart from Best et al. (2023) by analyzing the role of the individual in the procurement of *services*, specifically highway infrastructure. For the procurement of goods, the role of a procurement official is primarily constrained to the bid letting and bid evaluation; there is no role for the individual to impact costs after the auction. In the case of highway procurement, DOT engineers can impact costs with their efforts throughout the pre-bidding, bidding and the post-auction (construction) phases.

Consider again the schematic in Figure 7. At the pre-bidding stage, project engineers can affect realized costs by developing detailed project plans, thereby decreasing risk to the contractor, potentially decreasing the winning bid and avoiding future change orders. Next, the office engineer can affect costs in the bidding stage with bidder outreach to increase participation, thereby potentially decreasing the winning bid. In the bid evaluation phase, the construction engineer and project manager evaluate bids, and can reduce costs by identifying inexperienced contractors or manipulated bids. Lastly, in the construction phase, the resident engineer can work to control cost overruns and delays, which often prevent projects from being completed on time and at cost. Although we do not observe every potential engineer who contributes to each project, we do have the identities of two important employees: the engineer that manages the project from inception to completion (the project man-

[62]The typical tasks include "prepares and presents information to the public about all types of transportation engineering matters; tests for and prepares environmental reports, assessment reports of transportation surveys, investigations and analysis statements, and air and water quality reports."

[63]Typical tasks include "supervises the preparation of transportation and encroachment permits; presents information to the public on transportation engineering matters; represents the Department of Transportation at meetings; prepares correspondence and reports."

ager), as well as the engineer that manages the construction phase (the resident engineer). Therefore, we will be able to separately identify the role of engineer quality at these two levels.

Measuring Engineer Quality We merge our project delivery data with the construction data to create a dataset of projects where we can identify both the resident engineer and the construction manager. This is about 2,400 projects between 2011 and 2018, which include almost 500 unique resident engineers and over 300 project managers. Given the size of the dataset and the number of individuals, we parameterize engineer quality instead of using a fixed effects approach.

We define compensation as the sum of salary and benefits observed for each engineer-year pair in the Transparent California data. A simple regression of job title and year dummies on compensation explains over 80% of the variation in the data (Appendix H.2). The residual is what we will attribute to "quality." We view our quality measure as capturing higher compensation due to both experience and quality of the employee. We know that salary progresses as a function of both of these underlying variables, which we do not observe independently. Engineer salary in California is dictated by rigid pay ranges within job titles. Employees can receive raises by moving within pay ranges and across job titles with experience and investment in their own quality.[64] We show in the appendix that our quality measure correlates well with alternate measures of experience (years on the job), which we only have for a subset of the sample.[65]

Empirical Approach Given our measure of engineer quality, the analysis is straightforward. We take the project-level outcome as a function of the engineer quality and a set of fixed effects. Each project, i, is indexed by project characteristics: the project type, p, the county, c, the route, r, the district, d, and the year t. Subscript j indexes the job title of the resident engineer assigned to the project. The full specification is as follows:

$$\begin{aligned} Y_{ijprcdt} =& \beta_1 \text{ Quality RE}_{ijdt} + \beta_2 \text{ Quality PM}_{ijdt} + \beta_3 \text{ Quality RE}_{ijdt} \times \text{Quality PM}_{ijdt} \\ &+ \alpha_j + \psi_p + \nu_r + \phi_c + \gamma_d + \phi_t + \epsilon_{ijprcdt}. \end{aligned} \tag{1}$$

The coefficients of interest are β_1, the effect of the quality of the resident engineer on the project, β_2, the effect of the quality of the project manager on the project, and β_3, the effect of the interaction of both resident engineer and project manager quality.

A concern for our analysis of the role of individual engineers' quality is the endogenous assignment of engineers to projects. If less experienced/lower quality engineers are assigned to more complicated

[64] See Appendix Section H.2 for a further discussion of the data, institutional details, and pay scale for Caltrans engineer.

[65] See Appendix Table H.3.

projects, this would bias our results upwards, and the positive relationship would be due to the assignment mechanism, not the effect of quality. However, all of the institutional details suggest the opposite—more experienced and qualified engineers should be assigned to more complicated projects. In Appendix H.1, we present evidence to this effect, which comes from the Caltrans construction handbook, data on experience and bids, and conversations with senior Caltrans officials. An engineer is assigned to a project based on his or her experience, as well as the project complexity, type, and location. We do our best to control for this assignment with project type, county, and route fixed effects, but we also see that senior resident engineers are assigned to more costly projects, so we control for the resident engineer job title.[66]

Results Table 5 shows the results. We have three outcomes of interest: total project cost, cost overrun, and project duration. For the cost and duration measures, the outcome is normalized by the size (mileage) of the project. Cost overrun is the percentage difference between the amount actually paid to the contractor (the total cost) and the original winning bid of the contractor. The engineer "quality" measure is standardized, with mean zero and unit variance.

The first set of results, the top panel of Table 5, shows the relationship between quality and project cost per mile. Here, resident engineer quality does not seem to affect realized costs independently. However, the quality of the project manager is strongly negatively correlated with costs. A one standard deviation increase in the experience of the project manager is associated with a 11% decrease in cost per mile, across specifications. Further, the quality of the resident engineer can also reduce costs, conditional on the quality of the project manager. Having a high quality resident engineer and project manager together further decreases costs. This is striking: the resident engineer can only further reduce costs when the project manager is also of high quality. This suggests that the benefits of quality of the construction engineer may be constrained by the project planning and bid-letting phases that occur before the construction even begins.

The next set of results, in the middle panel of Table 5, concerns cost overruns. Here, we find that only the quality of the resident engineer matters. This is not entirely surprising—the resident engineer can directly affect cost overruns via managing change orders and project timelines with the contractor. According to our conversations with Caltrans engineers, the project manager is not very involved in the construction phase. We note that the statistical significance of the resident engineer effect increases with the addition of county and route fixed effects, which suggests that engineer assignment can bias the results against finding an effect. Column (9) reports that a one standard deviation increase in

[66] Appendix H.3 describes how we classify project types.

Table 5: Engineer Quality and Project-Level Costs

	log(Cost per Mile ($))								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Quality RE	0.018		0.025	-0.005		0.004	0.003		0.009
	(0.035)		(0.031)	(0.031)		(0.029)	(0.042)		(0.037)
Quality PM		-0.114**	-0.115**		-0.117**	-0.117**		-0.109**	-0.111**
		(0.039)	(0.037)		(0.040)	(0.039)		(0.046)	(0.046)
Qual. RE × PM			-0.070**			-0.073**			-0.074*
			(0.031)			(0.032)			(0.035)
Adj. R-squared	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.21
R-squared	0.22	0.22	0.22	0.25	0.25	0.25	0.31	0.31	0.31
Observations	1,733	1,733	1,733	1,729	1,729	1,729	1,687	1,687	1,687
	Cost Overrun (%)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Quality RE	-6.376		-5.851	-8.571+		-7.951+	-9.798*		-9.116*
	(5.856)		(5.570)	(5.429)		(5.007)	(5.310)		(5.043)
Quality PM		-15.928	-15.711		-15.548	-15.259		-15.882	-15.649
		(19.437)	(19.268)		(19.679)	(19.672)		(20.998)	(21.234)
Qual. RE × PM			0.383			-1.379			-3.255
			(3.547)			(3.078)			(2.818)
Adj. R-squared	0.22	0.22	0.22	0.22	0.23	0.23	0.24	0.24	0.25
R-squared	0.23	0.24	0.24	0.26	0.27	0.27	0.33	0.34	0.34
Observations	2,013	2,013	2,013	2,010	2,010	2,010	1,943	1,943	1,943
	Duration (Days per Mile)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Quality RE	0.635		1.940	0.267		2.013	-14.934		-13.788
	(13.067)		(12.684)	(14.007)		(14.234)	(17.700)		(17.530)
Quality PM		-27.164	-26.977		-25.535	-25.288		-25.102	-24.590
		(20.679)	(19.645)		(22.966)	(21.929)		(22.019)	(21.200)
Qual. RE × PM			-13.137			-13.888			-11.379
			(8.938)			(9.521)			(11.970)
Adj. R-squared	0.12	0.12	0.12	0.11	0.11	0.11	0.15	0.15	0.15
R-squared	0.14	0.14	0.14	0.17	0.17	0.17	0.28	0.28	0.28
Observations	1,481	1,481	1,481	1,478	1,478	1,478	1,442	1,442	1,442
Proj. Type FE	×	×	×	×	×	×	×	×	×
Job Title FE	×	×	×	×	×	×	×	×	×
District FE	×	×	×	×	×	×	×	×	×
Year FE	×	×	×	×	×	×	×	×	×
County FE				×	×	×	×	×	×
Route FE							×	×	×

Notes: The table presents the results of estimating Equation 1. Columns (1) - (3) only include job title, project type, district, and year fixed effects. Columns (4) - (6) adds the county fixed effects, and columns (7) - (9) add route fixed effects. The outcome and quality variables are winsorized at the 1% level, with the exception of cost overrun, which is censored at 500% (the 88th percentile). Slight differences in availability of cost, mileage, and duration outcomes explain differences in the number of observations between the three outcome variables. Quality for both the resident engineer (RE) and project manager (PM) are standardized to have mean zero and unit variance. Appendix H.2 provides more details on our quality measure. Standard errors are clustered at the district level. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15.

resident engineer quality correlates with a 9.1 percentage point decrease in overrun, which is large. However, a few projects have very large cost overruns: the mean in the sample is about 84.2% and the median is 7.7%.[67] This overrun result is driven by low quality engineers presiding over projects with the largest cost overruns. When we restrict the sample to projects with at most a 200% cost overrun, which includes over 80% of the sample projects, the result disappears.[68]

Finally, we use the construction duration (days per mile) as an outcome. Here, we find noisy negative effects on duration, but the results are not statistically significant, for either the resident engineer or project manager.

6.4 Retirements and District-Level Costs

Next, we exploit variation in capacity arising from engineer retirements. Past work has studied how employee departures affect productivity, though largely through the lens of increased workload. Bajari and Tadelis (2001) develop a model of procurement contracts, inspired by stylized facts from the private-sector construction industry. One feature of the model is that busier procurement officers write less complete contracts, leading to more renegotiations ex-post. Warren (2014) brings this theory to the data, in the setting of federal procurement. He finds that retirement-induced workload spikes increase the risk of renegotiation and increase costs.[69,70]

In this section, we exploit variation in retirements of engineers across Caltrans districts. However, we do not use this variation as an instrumental variable for employment (unlike Warren (2014) and Giuffrida and Raiteri (2023)). We are not primarily interested in how retirements affect employee workload; we are interested in the loss of institutional knowledge that departs the district with the retirement.[71] Even if the DOT is hiring new engineers to fill the retirements immediately, the new engineers will have much less experience and, as a result, capacity will have decreased.[72] Therefore we will study the direct effect of retirement, as a proxy for capacity loss, on procurement outcomes.

[67] Cost overruns in California have increased significantly over the sample period of 2000-2018.

[68] In that specification, both project managers and resident engineers have small negative effects on overruns (-0.3 and -0.4 percentage points, respectively), which are not statistically significant.

[69] Here, Warren (2014) uses retirements as an instrumental variable for the number of procurement officers at an agency, and then leverages variation across and within agencies. Identification relies on the assumption that retirements are only related to procurement contracts and outcomes via employment. Past work has found that civil service retirements are largely driven by pension rules, and that retirements spike at age thresholds (Asch et al., 2005).

[70] We also note that managers and agencies should be able to forecast who is retirement eligible and adjust both workload of projects and staffing decisions accordingly. For this reason, Giuffrida and Raiteri (2023) use *unanticipated* retirement shocks as a shifter of procurement officer workload, where the unanticipated retirement shock is the difference between the actual and eligible number of retirements in a year. However, we are not only interested in the workload effect of retirements.

[71] We are interested in plausibly exogenous shifts in district employee *quality*, similar to Decarolis et al. (2020).

[72] The quotes at the start of the section make it clear that even anticipated retirements can signal a loss of capacity.

Retirement Shocks We construct a "retirement shock" as the share of engineers that retire in each district-year. The numerator is the number of retirements in the district-year. The denominator is more complicated because we do not have district-year engineering employment over time. Instead, we use the total number of engineers statewide in a base year multiplied by the district's share of all awarded projects in the base year.[73] Ideally, our base year would be 2000, but we use 2011 because it is the first year we have access to employment records. A shock value of 100 means that a number of engineers roughly equivalent to 100% of the district's 2011 staff retired that year. Appendix Figure H.4 shows the distribution of retirement shocks—the mean is 2.1% and the standard deviation is 1.7%.[74]

Empirical Approach We estimate the following equation, which takes the measures of district-level procurement outcomes as a function of the retirement shock. This captures whether a larger than average retirement shock increases the duration and cost of projects started in year t:

$$Y_{dt} = \beta_0 + \beta_1 \frac{\text{Retirements}}{\text{Engineers}}_{dt} + \beta_2 \ \#\ \text{of Projects}_{dt} + \gamma_d + \phi_t + \epsilon_{dt}. \tag{2}$$

The regression includes district (d) and year (t) fixed effects, and includes a control for the number of projects starting in that year. The district fixed effects control for time invariant omitted variables at the district level, while the year fixed effects control for time-varying shocks at the state level.

An identification assumption is that retirements only affect procurement outcomes via the loss of capacity (experience and, potentially, staffing), not through another channel. Retirements of civil servants are largely driven by the attainment of the pension age thresholds (Asch et al., 2005; Giuffrida and Raiteri, 2023). If civil servants are retiring in order to avoid more complicated projects, this would create a positive bias for our results. However, our results are robust to controlling for the mix of project type, suggesting that it is not a change in the complexity of the projects that drives our findings. Additionally, identification requires that there are no time-varying, district-specific, shocks that cause both retirements and lengthier projects. We cannot disprove the existence of such a shock but struggle to find a convincing example of such an event in our context.

Results Table 6 shows the results. A one percentage point increase in the retirement shock leads to a 10.6 day increase in project duration at the mean, and 8.1 days at the median. The average project takes one year to complete (285 days at the median), so this change represents a 2.9% increase at the mean (2.8% at the median). The effect on total costs translates to a 4.3% increase on the district-level

[73] We have statewide employment of engineers, so we also have to adjust for the fact that not all engineers are assigned to a district, some work at Caltrans Headquarters. We know from the pension data that this is about 20%.

[74] When we only use staff engineers (i.e. "Transportation Engineer (Civil)") to create the retirement shock, the mean is 1.7% and the standard deviation is 1.4%.

Table 6: Engineer Retirements and District-Level Procurement Outcomes

	Duration		log(Total Cost ($))		Overrun (%)	
	Mean	Median	Mean	Median	Mean	Median
	Retirement Sample: All Engineers					
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	10.569**	8.076+	0.043+	0.032	0.237	0.279**
	(3.984)	(5.041)	(0.027)	(0.027)	(0.206)	(0.106)
R-squared	0.69	0.67	0.73	0.71	0.60	0.60
	Retirement Sample: Staff Engineers					
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	11.735***	7.564+	0.043**	0.023	0.380*	0.351**
	(3.704)	(4.367)	(0.018)	(0.015)	(0.204)	(0.149)
R-squared	0.70	0.66	0.73	0.71	0.60	0.61
	Retirement Sample: Senior Engineers					
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	2.117	2.079	0.016	0.019	-0.065	0.007
	(1.808)	(1.782)	(0.015)	(0.018)	(0.084)	(0.034)
R-squared	0.69	0.66	0.73	0.71	0.60	0.59
Observations	228	228	228	228	228	228
District FE	×	×	×	×	×	×
Year FE	×	×	×	×	×	×
Dep. Var. Mean	365.53	285.54	13.90	13.75	6.80	4.90

Notes: The table presents a simple regression of the district-level retirement shock on district-level procurement outcomes (duration, project cost, and cost overrun), as specified in equation 2. All regressions include District and Year FE. The independent variable of interest, $\frac{\text{Retirements}}{\text{Engineers}}$, is measured as a percentage. There are 3 sets of regressions: the first uses any engineer retirement in the district, the second only uses "staff" engineer retirements, and the third only uses "senior" engineer retirements. For each of these shock variables the denominator is the estimated number of engineers of that type in that district in the base year. The results are robust to restricting the sample to resurfacing and to controlling for the composition of project types at the district-year level. Standard errors are clustered at the district level. ***p < 0.01, **p < 0.05, *p < 0.1, +p < 0.15.

mean, but is not significant at the median. The median cost overrun is 4.9% over the districts in Caltrans. Therefore, districts with a one percentage point increase in retirement shock experience a 5.7% increase in cost overruns, at the median.[75] These results show that costs and duration increase for projects that *start* in the same year as the retirements, but we do not find that the results persist for projects started in the next year.

Table 6 also shows the result by the "type" of retirement. We define two types: "Staff" and "Senior." Staff engineers, as described in the previous section, have the job title "Transportation Engineer (Civil)," and are the majority of the engineers in the sample. Senior Engineers have more

[75]In this analysis, we use the total cost and total duration instead of per-mile, which was the relevant outcome in the engineer quality analysis. Here, the analysis is at the district instead of project level, so we are not concerned about standardizing each project to make them comparable. However, there could be changes in the scope of the projects that coincide with retirements. We show in Appendix Table H.7 that this is not the case; there is no effect of retirements on project mileage or number of projects let, and the coefficient on retirement shock for median log(cost per mile) is larger than for median log(cost).

management responsibilities and retire with slightly more years of experience upon retirement. The results using only the "staff" engineers are even stronger than the full sample, while the results using only the retirements of "seniors" show no effects. A one percentage point increase in the retirement shock for staff engineers is associated with a 11.7 day increase in mean duration (3.2%), 4.3% increase in mean costs, and a 0.38 percentage point increase in mean overrun (5.6%). The mean retirement shock for "staff" engineers is 1.7% and the standard deviation is 1.4%.

We can benchmark the district-level retirement results against the individual-level engineer analysis. In the engineer analysis we see one standard deviation increase in project manager experience decreases costs by about 11%. We simulate a 1% retirement shock through the district-years in the retirement data. We assume that the shock implies a 1 standard deviation loss of experience (i.e., an 11% cost increase) for one project for each retiring engineer, and that the retiring engineers would be assigned to the largest projects (i.e., the highest winning bids).[76,77] We find that under these assumptions, a one percentage point retirement shock would increase total costs by 6.5% at the mean. We note that in the individual engineer analysis, we did not find a significant effect of engineer quality on duration, and, except in the tail, on cost overrun. The results on duration and overrun that we find in the district-level retirement analysis can also be driven by workload effects.

These results suggest that this is not primarily a story about a loss of capacity at upper levels of management. The supervising transportation engineers and deputy directors are not directly staffed on projects. Instead, it is the staff engineers that are delivering the project—drawing up project plans, creating cost estimates, communicating on the ground with the contractor, and even acting as the project manager—that drive the results. These engineers are an essential input to day-to-day Caltrans operations and have direct effects on timely project completion, as well as costs. When the staff engineers retire, anticipated or not, outcomes suffer. The qualitative evidence from the survey provides some insight on why, such as losing hard-to-replace expertise from long experience on the job. Lags in replacing even anticipated retirees that result from bureaucratic state hiring practices may also contribute.

7 Conclusion

It is very expensive to build and maintain infrastructure in the United States. The biggest reasons remain unclear, partly due to difficulties in collecting data and comparing projects. We create two

[76] We note that our engineer quality measure is about one standard deviation higher in the last year we observe an engineer in the data than in the first year (a difference of $10,000 at the median and $8,000 at the mean).

[77] Appendix Figure H.1 shows that this is true in the construction data: resident engineers years of experience is strongly positively correlated with winning bid per mile.

new data sets to answer this question. The data allow us to actually measure infrastructure costs at the project level and document differences in the procurement and delivery of infrastructure at the state level. We hope that the new data we produce with this paper will be a useful tool for further work on this topic.

Two themes arise from our study. The first is the role of DOT capacity as a cost driver. DOT employment has decreased by about 20% in the last 20 years. We find that DOTs that provide more details at the time of the bid-letting have lower costs, while states with more change orders, which are often the result of poor planning, have higher costs. Consultant use, a symptom of low in-house capacity, is correlated with higher costs.

The second is the role of competition as a cost driver. This is evident from the survey and the administrative data—bidders know the identity and capacity of their competitors at the time of the bid-letting, DOTs do very little bidder outreach, and there are fewer construction firms in most states than there were 10 years ago. Further, the number of bidders, and the DOT propensity to do outreach, correlate with lower realized costs. It may very well be that competition is a function of agency capacity—we find evidence that higher capacity DOTs (as measured by reported quality) do more bidder outreach and have slightly higher levels of bidders.

Motivated by these findings, we use detailed personnel data from the state of California to study the relationship between capacity and infrastructure costs. We find that employee quality is an important input: projects with higher quality engineers cost less, and when DOT districts experience a large retirement shock, costs and project durations increase.

The results show the value of survey methods and correlations to uncover important suggestive findings that would not have been attainable from studying quasi-experimental variation in particular auction practices. It turned out here that the descriptive and correlational results pointed to state capacity, which indicated that seeking out quasi-experimental variation on staff retirements could be promising.

More generally, the scope of the state is a fundamental issue across the world (e.g., Besley and Persson, 2010). Having excessive state capacity is wasteful or even dangerous. But having too little state capacity—in the form of too few employees, burdened by too many rules, for example—can be wasteful too (Pahlka, 2023). As long as the government is providing public goods, the government needs to have enough capacity to operate effectively. As rising fiscal pressures cause governments across the country and world to reduce costs, the results raise a cautionary note: be careful, since expensive government provision can get even more expensive if governments lack the ability to plan, contract, and supervise well.

References

Allende, Claudia, Pablo Atal, Rodrigo Carril, Ignacio Cuesta, and Andres Gonzalez-Lira. 2023. "Drivers of Public Procurement Prices: Evidence from Pharmaceutical Markets."Technical report, Working Paper.

American Society of Civil Engineers. 2021. "Infrastructure Report Card."Technical report, Accessed 10/31/24: `www.infrastructurereportcard.org`.

Asch, Beth, Steven J. Haider, and Julie Zissimopoulos. 2005. "Financial incentives and retirement: evidence from federal civil service workers." *Journal of Public Economics*, 89(2): 427–440.

Bajari, Patrick, Stephanie Houghton, and Steven Tadelis. 2014. "Bidding for Incomplete Contracts: An Empirical Analysis of Adaptation Costs." *American Economic Review*, 104(4): , p. 1288–1319.

Bajari, Patrick, and Steven Tadelis. 2001. "Incentives versus Transaction Costs: A Theory of Procurement Contracts." *The RAND Journal of Economics*, 32(3): 387–407.

Bajari, Patrick, and Lixin Ye. 2003. "Deciding Between Competition and Collusion." *The Review of Economics and Statistics*, 85(4): 971–989.

Balat, Jorge. 2012. "Highway Procurement and the Stimulus Package: Identification and Estimation of Dynamic Auctions with Unobserved Heterogeneity."Technical report, Working Paper.

Bandiera, Oriana, Michael Carlos Best, Adnan Qadir Khan, and Andrea Prat. 2021. "The Allocation of Authority in Organizations: A Field Experiment with Bureaucrats*." *The Quarterly Journal of Economics*, 136(4): 2195–2242.

Bandiera, Oriana, Andrea Prat, and Tommaso Valletti. 2009. "Active and Passive Waste in Government Spending: Evidence from a Policy Experiment." *American Economic Review*, 99(4): 1278–1308.

Barrus, David, and Frank Scott. 2020. "Single Bidders and Tacit Collusion in Highway Procurement Auctions." *The Journal of Industrial Economics*, 68(3): 483–522.

Besley, Timothy, and Torsten Persson. 2010. "State Capacity, Conflict, and Development." *Econometrica*, 78(1): 1–34.

Best, Michael Carlos, Jonas Hjort, and David Szakonyi. 2023. "Individuals and Organizations as Sources of State Effectiveness." *American Economic Review*, 113(8): , p. 2121–67.

Bolotnyy, Valentin, and Shoshana Vasserman. Forthcoming. "Scaling Auctions as Insurance: A Case Study in Infrastructure Procurement." *Econometrica*.

Bosio, Erica, Simeon Djankov, Edward Glaeser, and Andrei Shleifer. 2022. "Public Procurement in Law and Practice." *American Economic Review*, 112(4): 1091–1117.

Boylan, Richard T, and Cheryl X Long. 2003. "Measuring Public Corruption in the American States: A Survey of State House Reporters." *State Politics & Policy Quarterly*, 3(4): 420–438.

Brooks, Leah, and Zachary Liscow. 2023. "Infrastructure Costs." *American Economic Journal: Applied Economics*, 15(2): 1–30.

Carril, Rodrigo, Andres Gonzalez-Lira, and Michael S. Walker. 2022. "Competition under Incomplete Contracts and the Design of Procurement Policies."Technical report, Working Paper.

Clark, Robert, Decio Coviello, Jean-François Gauthier, and Art Shneyerov. 2018. "Bid Rigging and Entry Deterrence in Public Procurement: Evidence from an Investigation into Collusion and Corruption in Quebec." *The Journal of Law, Economics, and Organization*, 34(3): 301–363.

Clarke, Damian, Joseph P Romano, and Michael Wolf. 2020. "The Romano–Wolf Multiple-Hypothesis Correction in Stata." *The Stata Journal*, 20(4): 812–843.

Coviello, Decio, and Mario Mariniello. 2014. "Publicity requirements in public procurement: Evidence from a regression discontinuity design." *Journal of Public Economics*, 109(C): 76–100.

Currier, Lindsey, Edward L Glaeser, and Gabriel E Kreindler. 2023. "Infrastructure Inequality: Who Pays the Cost of Road Roughness?" Working Paper 31981, National Bureau of Economic Research.

De Silva, Dakshina, Timothy Dunne, Anuruddha Kankanamge, and Georgia Kosmopoulou. 2008. "The impact of public information on bidding in highway procurement auctions." *European Economic Review*, 52(1): 150–181.

Decarolis, Francesco, Leonardo M Giuffrida, Elisabetta Iossa, Vincenzo Mollisi, and Giancarlo Spagnolo. 2020. "Bureaucratic Competence and Procurement Outcomes." *The Journal of Law, Economics, and Organization*, 36(3): 537–597.

Fajgelbaum, Pablo D, Cecile Gaubert, Nicole Gorton, Eduardo Morales, and Edouard Schaal. 2023. "Political Preferences and Transport Infrastructure: Evidence from California's High-Speed Rail." Working Paper 31438, National Bureau of Economic Research.

Federal Highway Administration. 2014,2018,2019. "Highway Statistics." `https://www.fhwa.dot.gov/policyinformation/statistics.cfm`.

Federal Transit Administration. 2022. "Capital Expenditures Time Series."

GAO. 2008. "Increased Reliance on Contractors Can Pose Oversight Challenges for Federal and State Officials."

Giuffrida, Leonardo M., and Emilio Raiteri. 2023. "Bureaucratic Frictions and Innovation Procurement." CESifo Working Paper Series 10775, CESifo.

Goldwyn, Eric, Alon Levy, Elif Ensari, and Marco Chitti. 2023. "Transit Costs Project."

Goolsbee, Austan, and Chad Syverson. 2023. "The Strange and Awful Path of Productivity in the U.S. Construction Sector."Technical report, NBER Working Paper 30845.

Government Performance Lab. 2016. "Reducing Budget and Timeline Overruns of Street Reconstruction Contracts in Saint Paul, Minnesota."Technical report, Harvard Kennedy School, `govlab.hks.harvard.edu`.

Gupta, Arpit, Stijn Van Nieuwerburgh, and Constantine Kontokosta. 2020. "Take the Q Train: Value Capture of Public Infrastructure Projects." Working Paper 26789, National Bureau of Economic Research.

Hjort, Jonas, Golvine de Rochambeau, Vinayak Iyer, and Fei Ao. 2020. "Informational Barriers to Market Access: Experimental Evidence from Liberian Firms." Working Paper 27662, National Bureau of Economic Research.

Jofre-Bonet, Mireia, and Martin Pesendorfer. 2003. "Estimation of a Dynamic Auction Game." *Econometrica*, 71(5): 1443–1489.

Krasnokutskaya, Elena, and Katja Seim. 2011. "Bid Preference Programs and Participation in Highway Procurement Auctions." *American Economic Review*, 101(6): 2653–86.

Kroft, Kory, Yao Luo, Magne Mogstad, and Bradley Setzler. 2022. "Imperfect Competition and Rents in Labor and Product Markets: The Case of the Construction Industry."Technical report, NBER Working Paper 27325.

Levin, Dan, and James Smith. 1994. "Equilibrium in Auctions with Entry." *American Economic Review*, 84(3): 585–99.

Levin, Jonathan, and Steven Tadelis. 2010. "Contracting for Government Services: Theory and Evidence from American Cities." *The Journal of Industrial Economics*, 58(3): 507–541.

Lewis, Gregory, and Patrick Bajari. 2011. "Procurement Contracting With Time Incentives: Theory and Evidence." *The Quarterly Journal of Economics*, 126(3): 1173–1211.

Lewis, Gregory, and Patrick Bajari. 2014. "Moral Hazard, Incentive Contracts, and Risk: Evidence from Procurement." *The Review of Economic Studies*, 81(3): 1201–1228.

Liebman, Jeffrey, and Hanna Azemati. 2016. "How Cities Can Improve Their Procurement of Goods and Services."Technical report, Manhattan Institute, `https://manhattan.institute/article/how-cities-can-improve-their-procurement-of-goods-and-services`.

Liscow, Zachary. 2024. "State Capacity for Building Infrastructure." In *Strengthening America's Economic Dynamism*. eds. by Melissa S. Kearney, and Luke Pardue, Washington, DC: Aspen Institute.

Liscow, Zachary, and Abigail Pershing. 2022. "Why Is So Much Redistribution In-Kind and Not in Cash? Evidence from a Survey Experiment." *National Tax Journal*, 75(2): 313–354.

Mehrotra, Neil, Matthrew Turner, and Juan Pablo Uribe. 2021. "Does the US have an Infrastructure Cost Problem? Evidence from the Interstate Highway System."Technical report, Working Paper.

Milgrom, Paul R., and Robert J. Weber. 1982. "A Theory of Auctions and Competitive Bidding." *Econometrica*, 50(5): 1089–1122.

National Academies of Sciences, Engineering, and Medicine. 2006. "Best-Value Procurement Methods for Highway Construction Projects."Technical report, Washington, DC: The National Academies Press.

Pahlka, Jennifer. 2023. *Recoding America: Why Government is Failing in the Digital Age and How We Can do Better.*: Metropolitan Books.

Porter, Robert, and John Zona. 1993. "Detection of Bid Rigging in Procurement Auctions." *Journal of Political Economy*, 101(3): 518–38.

Reason Foundation. 2018. "Annual Highway Report." Accessed 10/25/2020: `https://reason.org/topics/transportation/annual-highway-report/`.

Romano, Joseph P, and Michael Wolf. 2005a. "Exact and Approximate Stepdown Methods for Multiple Hypothesis Testing." *Journal of the American Statistical Association*, 100(469): 94–108.

Romano, Joseph P, and Michael Wolf. 2005b. "Stepwise Multiple Testing as Formalized Data Snooping." *Econometrica*, 73(4): 1237–1282.

Romano, Joseph P, and Michael Wolf. 2016. "Efficient Computation of Adjusted p-values for Resampling-Based Stepdown Multiple Testing." *Statistics & Probability Letters*, 113 38–40.

Rosenthal, Brian. 2017. "The Most Expensive Mile of Subway Track on Earth." *The New York Times*.

Rosenthal, Brian. 2018. "Why Does Subway Construction Cost So Much? Congress Wants to Find Out." *The New York Times*.

Ryan, Nicholas. 2020. "Contract Enforcement and Productive Efficiency: Evidence From the Bidding and Renegotiation of Power Contracts in India." *Econometrica*, 88(2): 383–424.

Tarrer, Gregory Whetstone, A. Ray, and James Boylan. 1995. "Impacts of Environmental, Health, and Safety Regulations on Highway Maintenance."Technical report, Proceedings of the Seventh Maintenance Management Conference.

US Census Bureau. 1997-2021. "Annual Survey of Public Sector Employment and Payroll." `https://www.census.gov/programs-surveys/apes.html`.

US Census Bureau. 2007,2012,2017. "Economic Census for Construction." `https://www.census.gov/data/tables/2017/econ/economic-census/naics-sector-23.html`.

Warren, Patrick L. 2014. "Contracting officer workload, incomplete contracting, and contractual terms." *The RAND Journal of Economics*, 45(2): 395–421.

Wolfram, Catherine, Edward Miguel, Eric Hsu, and Susanna Berkouwer. 2023. "Donor Contracting Conditions and Public Procurement: Causal evidence from Kenyan electrification."Technical report, NBER Working Paper 30948.

Appendix

A Procurement Process and Hypotheses

In this section we provide more details on the state DOT procurement process. We proceed chronologically, and highlight which practices at each stage of the procurement process have the potential to affect final highway construction costs.

The hypotheses are mostly from the industrial organization literature, which includes many specific case studies from a handful of states. However, the survey will also allow us to highlight cost drivers that have not been studied much in existing literature. For example, we can ask about how often the state DOT employs consultants, which is often mentioned in conversations with practitioners as a potential costly practice (Levin and Tadelis, 2010).

Outside of the procurement process, we also ask about DOT capacity and quality, to speak to the ability of the state to run an efficient procurement system and oversee road maintenance and construction. On the contractor side, we ask about firm size and experience, as well as their knowledge of their competitors and their investments in cost reductions.

A.1 Pre-Bidding

In the first stage, pre-bidding, the procuring entity (which is the state DOT here) assesses its procurement needs and budget. The DOT decides which projects to complete and the scope of each project (e.g., a project for 30 miles of road vs. three separate projects for 10 miles), and the state engineer estimates the cost of each project. State DOTs often plan highway construction projects 4 years or more in advance to conform with federal regulations.

Contractors' bids are higher when they are capacity constrained.

If there are only a few eligible contractors for a large complicated project, and these firms have capacity constraints, both the timing of projects and the size of the job have the potential to reduce the pool of potential bidders, reducing competition and driving up final procurement costs (Best et al., 2023; Jofre-Bonet and Pesendorfer, 2003).

For instance, timing procurement with aggregate demand shocks could take advantage of slack construction firm resources, although government stimulus may invert this effect. An examination of the 2009 ARRA stimulus package on highway construction found that the government paid prices that were 6.2% higher, due to the effect of stimulus projects on firms backlogs (Balat, 2012). Due

to capacity constraints, the firm that has already committed to an ongoing project will have to pay overtime wages or rent additional workers; competitors may increase their bids if they know their rivals are constrained.

A.2 Bid Letting: Announcing the Project and Collecting Bids

In the second stage, bidding, the DOT determines the procurement method, the information made public for the project, and how the bids will be collected. The procurement method has a direct effect on costs, as different auction designs correspond to different optimal bidding strategies (Milgrom and Weber, 1982). However, given our focus on road resurfacing, there is no variation in the actual auction design; we know all states use low-bid (first price) auctions.[78] However, the states do have discretion on where they post the project, whether they advertise it, and what information they include.

Providing detailed and accurate information on project plans reduces final costs.

There is no federal mandate dictating how much information a state DOT needs to provide to bidders. However, there is evidence that providing more information to bidders on the specifics of the project and engineer's estimate can reduce costs (De Silva et al., 2008). In effect, providing more detailed plans to bidders reduces uncertainty on construction costs which will result in realized costs being closer to the winning bid. The accuracy of these plans is also important: conversations with practitioners indicate to us that incomplete or incorrect plans can delay project completion or lead to costly renegotiation.

Providing detailed information on competing bidders can increase costs.

It is also possible that more information can increase costs, when this information facilitates collusion. For example, in Kentucky, the DOT made the names of firms that purchased bid proposals public the Friday before bids were due. This allowed firms to know if anyone was eligible to bid against them before submitting their actual bid (Barrus and Scott, 2020). The authors suggest that "the threat of even a second potential bidder in an auction [would lower] the winning bid by over ten percent, and that reforming the two-step procurement process, with its opportunity for gaming bids, could reduce costs for highway construction in Kentucky.

Efforts to increase the bidder pool can decrease costs.

Advertising the project and doing outreach to potential bidders can have substantial effects on the

[78] This is typical for road resurfacing and building projects that use federal funds, which are the focus of our survey. More complicated projects might be evaluated on price and quality. There is evidence that evaluating bids on quality, not only price, provides incentives for faster delivery (Lewis and Bajari, 2011).

level of entry (Krasnokutskaya and Seim, 2011; Levin and Smith, 1994) and the ability of incumbent bidders to collude (Bajari and Ye, 2003; Clark et al., 2018; Porter and Zona, 1993). It is well-established in the auction literature that increasing competition can reduce costs, and efforts in St. Paul, Minnesota has shown bidder outreach can achieve this effect (Government Performance Lab, 2016; Liebman and Azemati, 2016).

The DOT's level of outreach is not specific to the auction design, so it is not the focus of much of the IO procurement auction literature. An important contribution of our survey approach is to collect data on these procurement practices which may not be codified in state regulations but have the potential to substantially affect costs.

A.3 Submitting Bids and Project Award

After the bids are collected, the bids are evaluated and the contract is awarded.

Strict criteria to evaluate bids have the potential to decrease costs.

The common legislative requirement is to award highway construction using a low-bid system. However, procurement officials are generally wary of extremely low bids. These could be the result of the bidders attempting to win the contract for a low price, expecting to renegotiate a higher price at a later date. These could also be the result of an inexperienced bidder, not realizing what actual costs will be: unrealistically low bids[s], while appearing to be a real bargain, may in fact result from the bidder, or lack of competence to successfully complete the given project (National Academies of Sciences, Engineering, and Medicine, 2006). The procurement office can police "abnormally low bids by establishing a criterion to identify them, and then throwing out bids that are flagged as abnormally low or "mathematically unbalanced" (i.e., when a bid is unrealistic in its cost structure).

Strict criteria to evaluate bids have the potential to increase costs if overly burdensome.

During the bid screening process the procuring entity can exclude bids for other types of errors besides abnormally low bids. If the bidding process is too complicated it creates the possibility for bidders to make small technical mistakes that disqualify otherwise qualified bids (Best et al., 2023). Trivial reasons to exclude bids in the bid screening process will artificially reduce competition, and increase costs.

A.4 Construction: Execution of the Contract

Execution concerns everything that happens in the period between the commencement of work and when the project is completed. This includes delays, contract renegotiation, payment, and inspection

of the final works.

Delays increase costs.

This is a well-known fact in the literature. Delays increase total project costs, and incur costs to commuters who would like to travel on the road that is being serviced. What are not as well established are the degree to which delays vary across states and the source of the delays. Our survey asks about the frequency of delays, the usual causes of delays, and about two specific processes that can cause delays: obtaining regulations and permits for work, and renegotiating the contract.[79] Recent work in the Kenyan setting show that more stringent certification and inspection requirements required by the World Bank led to substantial delays (Wolfram et al., 2023).

The renegotiation process causes realized costs to exceed winning bids.

Incomplete contracts can create a costly renegotiation process, which bidders might take advantage of when submitting bids in the bidding stage (Lewis and Bajari, 2014; Ryan, 2020). Completing any negotiation or change orders quickly will reduce delays, as discussed above. Beyond delays, the ability to renegotiate on costs can affect bidder strategy. Therefore, anything that the DOT does to constrain the renegotiation process can have an impact on costs.

Figure A.1: Contract Award and Unit Bidding

ARKANSAS
BY JOB REPORT

Oman Systems, Inc

Job No: 061084	County: HOT SPRING	100				
Low Bidder: ROBERTSON CONTRACTORS, INC.			Low Bid:	$7,045,842.59	Letting: 01/1	

				1st Bidder ROBERTSON CONTRACTORS, INC.	2nd Bidder MANHATTAN ROAD & BRIDGE CO.	3rd Bidder KIEWIT INFRASTRUCTURE SO. CO.	4th Bidder MOBLEY CONTRACTORS, INC.	State Average
PayItem	Description	Quantity	Unit	Unit	Unit	Unit	Unit	Unit
201011	CLEARING	25.000	STA-M	$800.00	$1,428.00	$3,500.00	$1,320.00	$1,318.16
201111	GRUBBING	25.000	STA-M	$800.00	$1,428.00	$3,500.00	$880.00	$903.49
401011	TACK COAT	406.000	GAL	$3.50	$3.50	$3.50	$3.68	$2.68
405161	MINERAL AGGREGATE IN ACHM BASE COURSE (1 1/2")	109.000	TON	$74.56	$74.56	$74.56	$78.29	$59.35
405402	ASPHALT BINDER (PG 64-22) IN ACHM BASE COURSE	5.000	TON	$120.00	$120.00	$120.00	$126.00	$205.32
406161	MINERAL AGGREGATE IN ACHM BINDER COURSE (1")	1472.000	TON	$76.44	$76.44	$76.44	$80.26	$62.09
406402	ASPHALT BINDER (PG 64-22) IN ACHM BINDER COURSE (1") (MINIMUM BID $120.00)	74.000	TON	$120.00	$120.00	$120.00	$126.00	$318.00
407162	MINERAL AGGREGATE IN ACHM SURFACE COURSE (1/2")	1832.000	TON	$78.88	$78.88	$78.88	$82.82	$65.82
407432	ASPHALT BINDER (PG 64-22) IN ACHM SURFACE COURSE (1/2") (MINIMUM BID $120. 00)	109.000	TON	$120.00	$120.00	$120.00	$126.00	$347.13
412001	COLD MILLING ASPHALT PAVEMENT	1289.000	S.Y.	$4.25	$5.20	$23.64	$16.49	$3.06

Notes: This figure shows an example of bids for a state DOT resurfacing project (this example is from Arkansas). Each contractor bids at the unit level, on a list of goods and services that are specified by the DOT. For example, in this project the DOT estimates that the contractor will need 406 gallons of tack coat and 5 tons of asphalt binder. The contractors' bids consist of a cost per item for each list on the unit bidding sheet, which are then multiplied by the quantities and aggregated. The contractor with the lowest bid wins the contract.

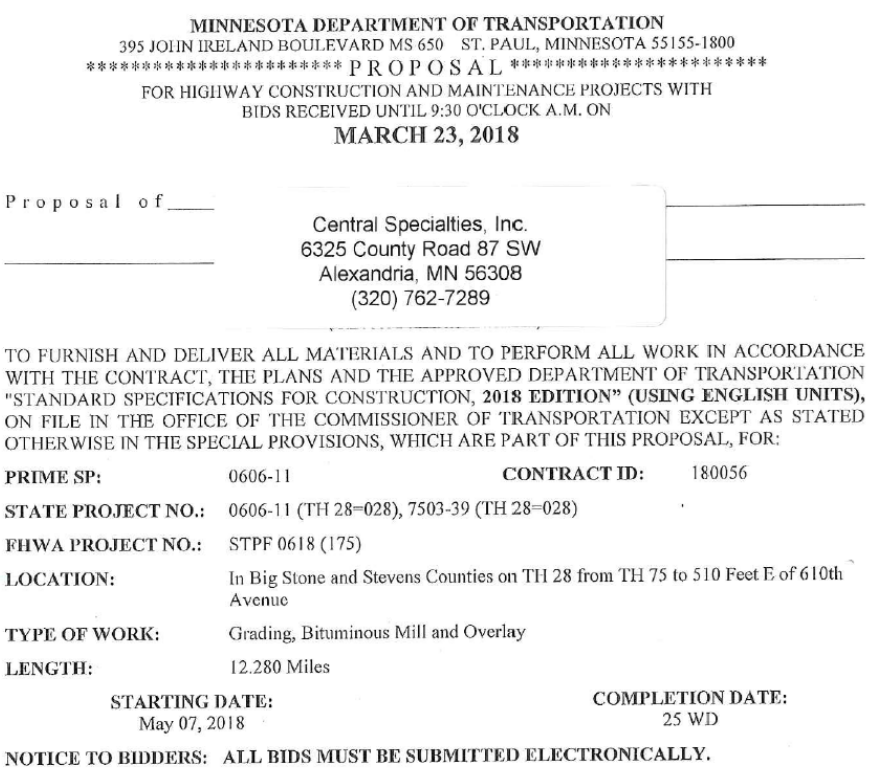
[79] After the passage of Resource Conservation and Recovery Act and subsequent regulation, Alabama DOT accepted bids for a project involving lead paint removal. One company that was aware of the regulations submitted a bid three times the size of a contractor that was unaware of the regulation changes (Tarrer and Boylan, 1995).

B Example Project

In order to give the reader some additional context, we go the details of a representative project in our dataset. This project is "grading, bituminous mill, and overlay" (per the project description, Figure B.1) for 12.28 miles of Minnesota State Highway 28. First the construction team needs to level the highway (grading), then the top layer of an existing bituminous (asphalt) road is removed using a milling machine, and lastly a fresh layer of asphalt is applied (overlay). Figure B.2 shows a snapshot of the process. Although these are small projects compared to bridge or subway construction, it is still relatively capital intensive.

As we described in Section 3.1, the state DOT plans the project, publishes those plans and a bid document for the contractor to fill out, and then evaluates the bids. Below in Figure B.1 we show a snapshot of the front page of the bid document, which summarizes the project. This is the type of information that we should either have in the data we request in the DOT, or we supplement with from online searches of bid documents. Figure B.1 further shows a snapshot of the project plans, which also would be included in the bid document. In this project, the bid document is 345 pages long (we discuss these documents further in Section 5.2).

Figure B.1: First Page of Bid Document



MINNESOTA DEPARTMENT OF TRANSPORTATION
395 JOHN IRELAND BOULEVARD MS 650 ST. PAUL, MINNESOTA 55155-1800
********** P R O P O S A L **********
FOR HIGHWAY CONSTRUCTION AND MAINTENANCE PROJECTS WITH
BIDS RECEIVED UNTIL 9:30 O'CLOCK A.M. ON
MARCH 23, 2018

Proposal of ____

Central Specialties, Inc.
6325 County Road 87 SW
Alexandria, MN 56308
(320) 762-7289

TO FURNISH AND DELIVER ALL MATERIALS AND TO PERFORM ALL WORK IN ACCORDANCE WITH THE CONTRACT, THE PLANS AND THE APPROVED DEPARTMENT OF TRANSPORTATION "STANDARD SPECIFICATIONS FOR CONSTRUCTION, **2018 EDITION" (USING ENGLISH UNITS),** ON FILE IN THE OFFICE OF THE COMMISSIONER OF TRANSPORTATION EXCEPT AS STATED OTHERWISE IN THE SPECIAL PROVISIONS, WHICH ARE PART OF THIS PROPOSAL, FOR:

PRIME SP:	0606-11	**CONTRACT ID:**	180056
STATE PROJECT NO.:	0606-11 (TH 28=028), 7503-39 (TH 28=028)		
FHWA PROJECT NO.:	STPF 0618 (175)		
LOCATION:	In Big Stone and Stevens Counties on TH 28 from TH 75 to 510 Feet E of 610th Avenue		
TYPE OF WORK:	Grading, Bituminous Mill and Overlay		
LENGTH:	12.280 Miles		

STARTING DATE: May 07, 2018 **COMPLETION DATE:** 25 WD

NOTICE TO BIDDERS: ALL BIDS MUST BE SUBMITTED ELECTRONICALLY.

Lastly, we have the result of the bidding process. There were 5 bidders in total, and they all submit unit bids. A snapshot of the unit bid submitted by the lowest bidder, Central Specialties, is shown in Figure B.4. This firm won the auction with a winning bid of $2.50 million. The final cost of the project, according to the data we collect from MNDOT, was only 3.2%, or $80,000, over, at $2.58 million.

Figure B.2: Mill and Overlay on MN State Highway 28



(a) Mill (b) Overlay (c) Finished Product

Figure B.3: Snapshot of Project Plans

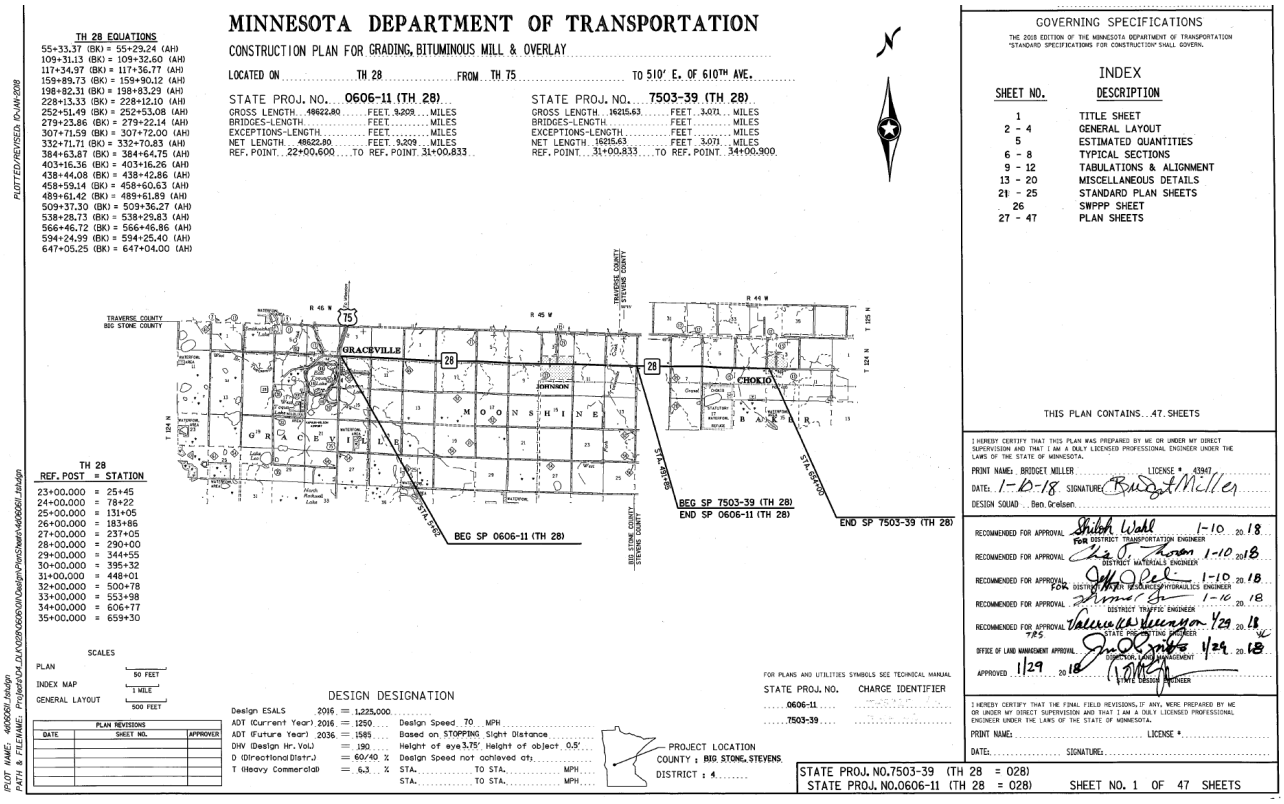


Figure B.4: Snapshot of Unit Bids

Minnesota Department of Transportation

Contract Schedule

Contract ID: 180056 **Project(s):** 120094, 127789

Apparent Low Bidder: 0000207897 Central Specialties, Inc.

SECTION 0001 **SP 0606-11** **$2,503,227.55**

Alt Set ID: **Alt Mbr ID:**

Proposal Line Number	Item ID / Description	Approximate Quantity and Units	Unit Price Dollars	Unit Price Cents	Bid Amount Dollars	Bid Amount Cents
0035	2104502/00130 REMOVE PIPE APRON	42.000 EACH	150		6,300.00	
0040	2104503/00195 SAWING CONCRETE PAVEMENT (FULL DEPTH)	264.000 L F	4		1,056.00	
0045	2104503/00205 SAWING BITUMINOUS PAVEMENT (FULL DEPTH)	411.000 L F	1.50		616.50	
0050	2104503/00255 REMOVE PIPE CULVERTS	934.000 L F	14		13,076.00	
0055	2104504/00070 REMOVE PAVEMENT	2,212.000 S Y	20		44,240.00	
0060	2104504/00120 REMOVE BITUMINOUS PAVEMENT	1,050.000 S Y	10		10,500.00	
0065	2105603/00060 DITCH CLEANING	1,351.000 L F	10		13,510.00	

C Descriptive Statistics for Table 1

Table C.1: Descriptive Statistics

	Obs.	Mean	Std. Dev.	Min.	Max.
Project Cost per Mile ($M)	250	0.37	0.51	0.01	5.19
Log(Project Cost per Mile ($M))	250	-1.48	0.96	-4.87	1.65
Project Details:					
Complex Dummy	250	0.06	0.24	0.00	1.00
Mileage	250	15.17	13.26	1.00	87.64
State Highway Dummy	250	0.66	0.47	0.00	1.00
Engineer's Estimate (Log(Cost/Mile))	94	-1.43	0.75	-3.13	0.29
Number of Bidders	250	3.36	1.49	1.00	9.00
Project DBE Goal (%)	153	4.72	5.14	0.00	22.00
Local Characteristics:					
Log(Population Density)	250	3.30	1.85	-2.25	8.88
Log(Wages in Hwy Construction)	250	4.36	0.38	3.55	5.51
State Characteristics:					
Precipitation	250	38.67	14.44	9.96	70.00
Winter Low	250	23.50	11.91	1.10	68.00
Snow Proxy	250	2.60	4.72	0.36	34.54
Summer High	250	83.61	6.07	60.20	94.20
Roughness Index	250	96.60	14.81	72.46	141.45
Hwy Employment per Capita (1,000)	250	0.92	0.63	0.23	3.25
State DBE Share	180	0.26	0.21	0.04	1.23
Bid Document Page Length	125	164.64	79.08	45.00	382.00

Notes: This table presents summary statistics of the variables used in Table 1, as well as other variables used in analyses. The project-level costs and characteristics (including number of bidders) are collected by the authors, and the data on other observables is described in detail in Appendix F. "Mileage" is measured in lane-miles (lanes × length of highway), "Complex" is a dummy to denote that the project involves work beyond a standard resurfacing job, and "State Highway" is a dummy to denote it is a state highway resurfacing project, as opposed to an interstate. "Precipitation" is the yearly precipitation total in inches for a given state, averaged over the period 2000-2019. "Winter Low" is the average state-level winter low temperature over 2000-2019, and "Summer High" is the average state-level summer high temperature over 2000-2019. "Roughness Index" is the average of a state-level roughness measure from the years 2014, 2018, and 2019. This comes from Highway Statistics (Federal Highway Administration, 2014,2018,2019). A larger value of "Roughness Index" corresponds to rougher roads. The "Engineer's Estimate" is the projected cost per mile (only available for 19 states). This is collected by the authors by manually searching the internet. Highway employment per 1,000 people is calculated from Census ASPEP and Census state population data. The DBE goal is a project-level variable that measures the % of the project that needs to be completed by a DBE firm. This is collected from the bid letting. The DBE share is a state-level variable that measures the number of construction firms registered as a DBE, as a share of the total number of construction firms. This is collected by the authors by downloading DBE registries in each state that it is available (36 states). Bid document page length is measured at the state level and is collected by the authors by manually searching for DOT bid document templates. See Appendix F.4 for more details on collecting the page length data.

D Cost Data

In this Appendix we review some additional descriptives on cost and compare our data with state-level aggregates provided by the Federal Highway Administration (FHWA).

D.1 Descriptives

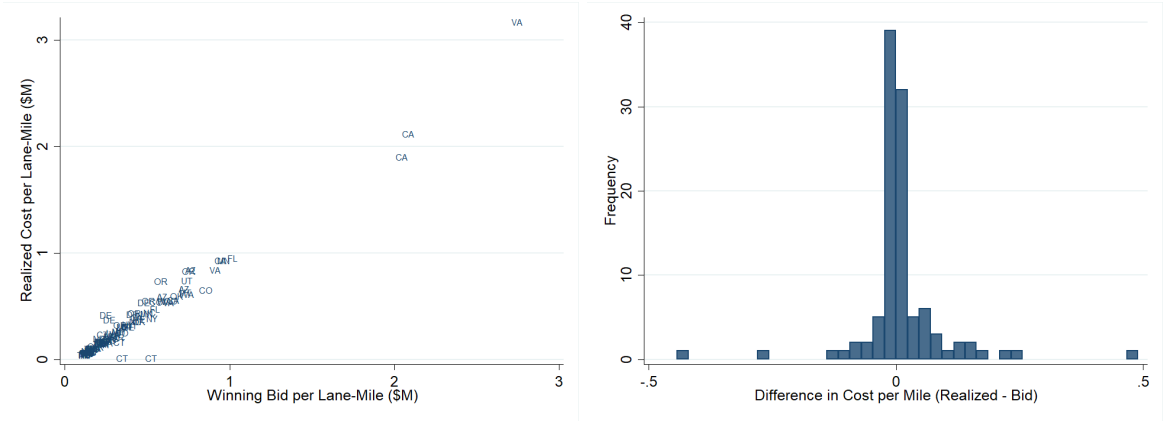
We request data on project-level costs directly from each state DOT. The states provide data in a variety of formats, and include different subsets of the variables that we request. For example, in some states we receive data on three cost variables: winning bid, realized cost, and amended contract cost. However, in some states we only receive one or two of the three. In the states that we only observe winning bid, for example, we want to be convinced that it is a good enough proxy for realized costs for the projects in our subsample.

Figure D.1 compares winning bids with realized costs, in the states where we have both (22 states). The panel on the left plots the two objects in the project-level data, and the panel on the right shows the differences, in a histogram. The two objects are highly correlated, with a correlation coefficient of 0.98.

Figure D.2 compares winning bids with "current contract" costs, in the states where we have both (17 states). Current contract costs are the winning bids plus or minus any contract amendments. Current contract costs are essentially realized costs, unless the project has not been completed. All of the projects in our data have been completed. The two objects are highly correlated, with a correlation coefficient of 0.99.

Our final sample uses the realized cost variable when available (23 states), then the current contract cost if available when realized cost is not (12 states), and the winning bid for the remainder (15 states). Figure D.3 shows the distribution of project costs across the sample and Figure D.4 shows the spending and length of the projects across space.

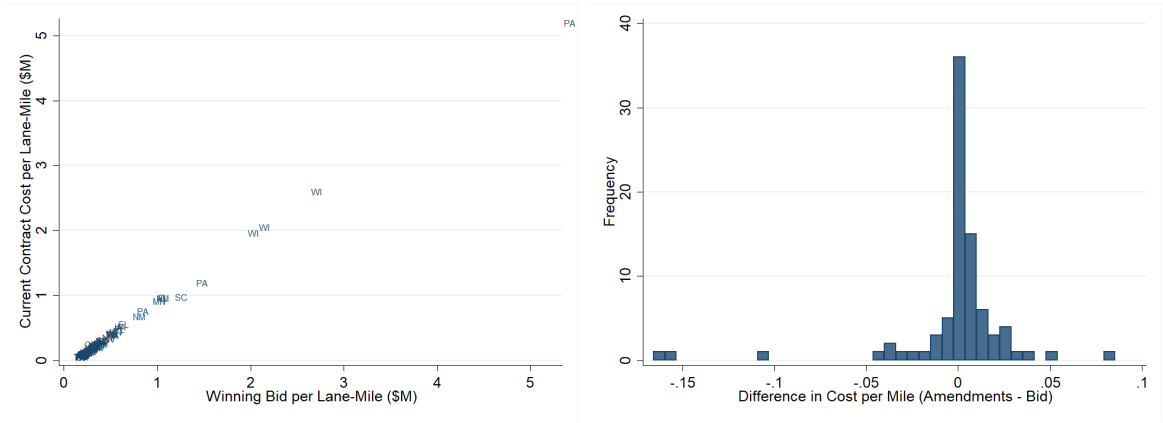
Figure D.1: Bids vs Realized Costs



(a) Comparison of Cost per Mile (b) Difference

Notes: This figure compares winning bids with realized costs. The panel on the left plots the two objects in the project-level data, and the panel on the right shows the differences, in a histogram. The two objects are highly correlated, with a correlation coefficient of 0.9812.

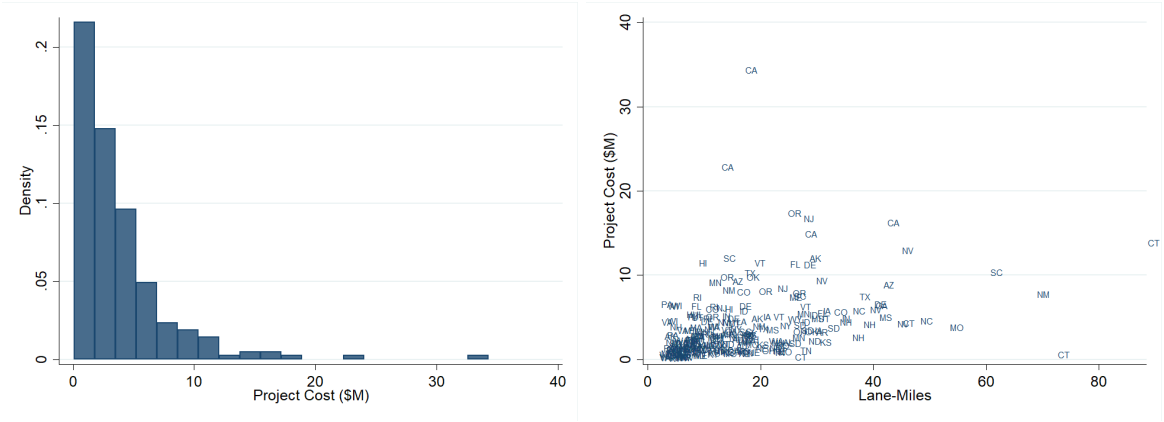
Figure D.2: Bids vs Amended Contracts



(a) Comparison of Cost per Mile (b) Difference

Notes: This figure compares winning bids with "current contract" costs. Current contract costs are the winning bids plus or minus any contract amendments. The panel on the left plots the two objects in the project-level data, and the panel on the right shows the differences, in a histogram. The two objects are highly correlated, with a correlation coefficient of 0.999.

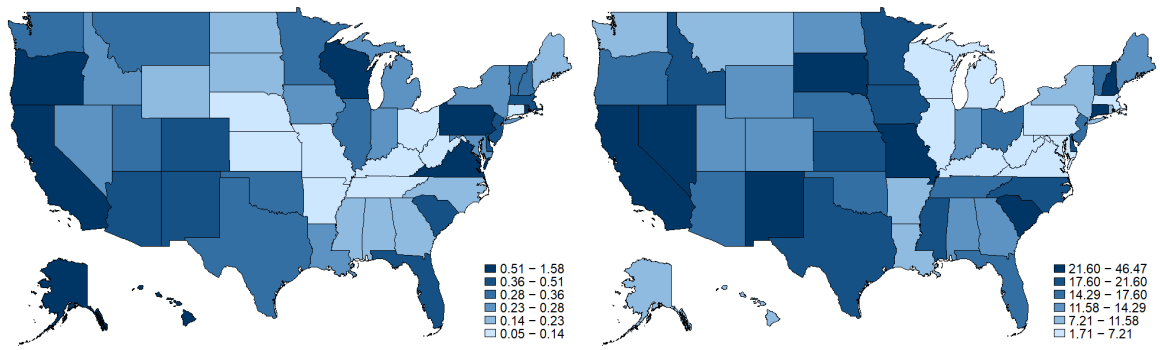
Figure D.3: Cost Data Sample: Totals



(a) Project-Level Total (b) Total vs Mileage

Notes: The histogram on the left shows the distribution of project-level costs in the data collected by the authors. The scatter plot on the right takes each project cost and plots it against total mileage of the project (in lane miles). The markers denote the state associated with the project One project that costs $62 million is not included, for visibility.

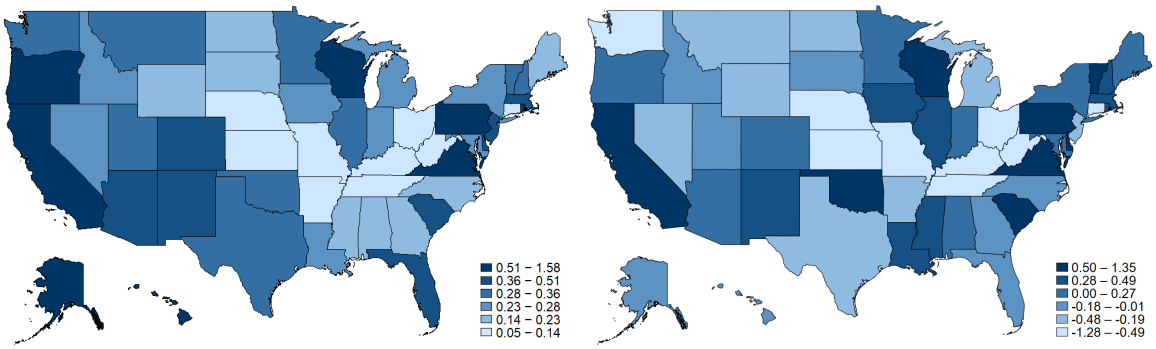
Figure D.4: Spending and Project Characteristics



(a) State-Level Spending (b) State-Level Mileage

Notes: The map on the left shows project costs per mile, and the right shows the mileage for these projects (reproduced from Figure 1 in the main text). The cost data collected by the authors is for resurfacing projects started in 2018 or 2019, with a length between 1 and 20 miles, on a non-interstate highway. There are 5 such projects per state, and the state average is used for this map. Interestingly, project length does seem to vary by state, with some states undertaking much longer projects, on average, than others.

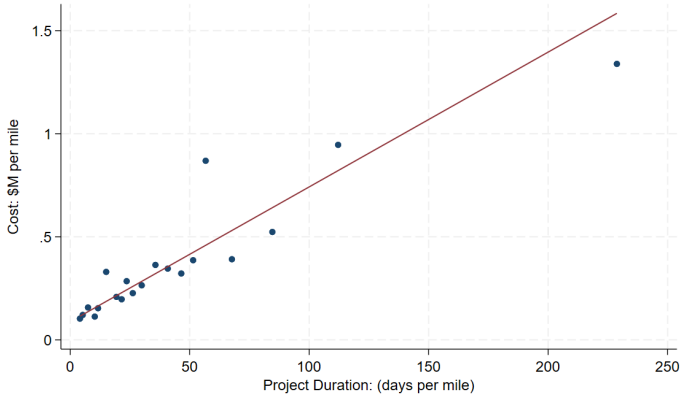
Figure D.5: Average Project Cost by State



(a) State-Level Cost per Mile ($M) (b) State-Level Residualized Cost per Mile

Notes: The figure on the left takes the average of project costs at the state level (reproduced from Figure 1 in the main text). The figure on the right displays the state-level average of residualized costs. Residual costs are determined using a project-level regression of project costs per lane-mile on the observables included in Column (2) of Table 1. Data collected by the authors.

Figure D.6: Costs and Project Duration

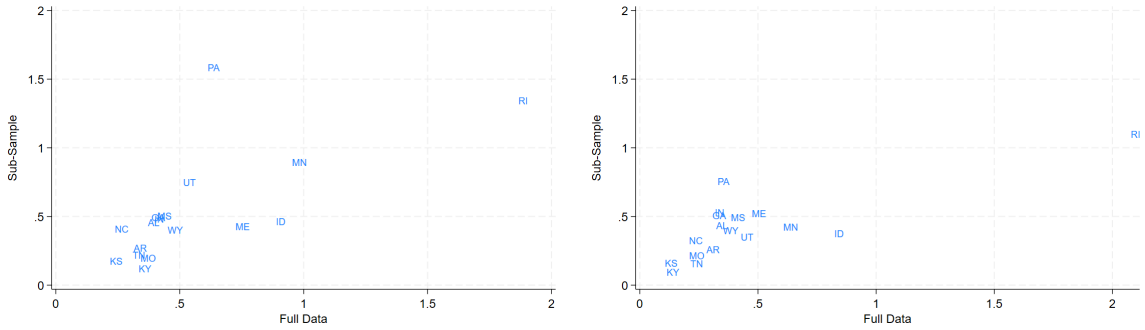


Notes: This is a binned scatter plot of project-level costs and duration. The y-axis shows the cost per lane-mile, in $M. The x-axis shows the duration per lane-mile, in days. The data was collected by the authors, as part of the project-level cost data. The project duration variable is only available for 33 states.

D.2 Comparing Our Subsample to All Available Data

For our main analyses, we use a subsample of projects to facilitate the collection of detailed information for each project. We obtained additional data on more projects for 22 states. Figure D.7 plots the mean and median cost per mile of our subsample against the mean and median cost per mile observed in the full data. For this comparison, we restrict the full data to match our selection criteria for the subsample (non-interstate resurfacing projects between 1 and 20 mile that began in 2018 or 2019). The correlation coefficient for mean cost per mile is 0.67 and the correlation coefficient for median cost per mile is 0.78. In this figure we restrict California, which is an outlier (the subsample data exhibits higher costs than the full sample). This allows us to visualize the remainder of the states. However, when we include all of the data from California in Table 1 we do not find different results.

Figure D.7: Subsample vs Full Data by State



(a) Mean Cost per Mile ($M)

(b) Median Cost per Mile ($M)

Notes: The figure on the left displays the mean cost per mile of our subsample versus the mean cost per mile of all available data, by state. The figure on the right performs the same comparison with median cost per mile. Both figures restrict to states with at least 5 projects observed in the full data. This leaves us with 18 states. California is omitted from both figures to better visualize the other states. Projects included in the subsample are excluded from the full data sample. Data collected by the authors.

D.3 Comparison with the FHWA Data

We can compare our data with state-level cost data from the Federal Highway Administration (FHWA). The FHWA requires states to report spending on a variety of categories and types of roads via an annual survey. As such, these data are self-reported by the states. A potential concern is that states do not all report resurfacing spending, for example, in the same narrow category. A second concern is that we do not have a denominator of miles resurfaced, we only have total miles in the state. Therefore, it is hard to know if cost per mile is higher in one state because they did more projects than another state or because the projects are more expensive. However, this is the only comprehensive dataset on state-level costs and is often used in reports about spending across states (e.g. Reason Foundation, 2018).

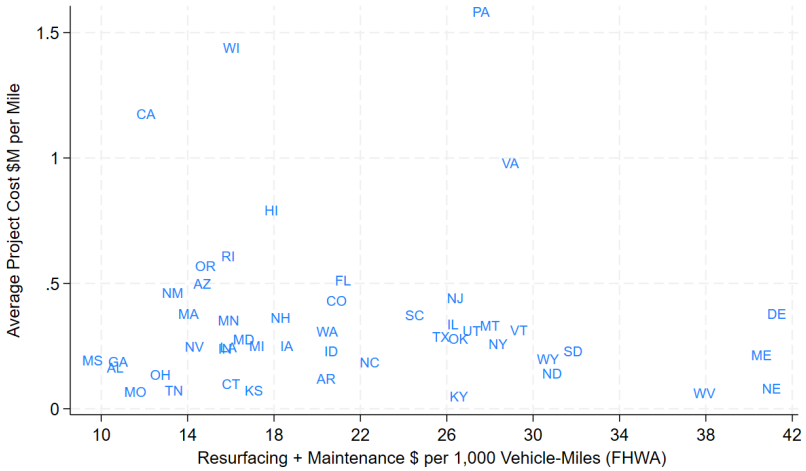
FHWA data includes spending by category, as we mentioned earlier. Therefore we need to select certain categories to compare with our sample of resurfacing projects. Due to potential reporting issues, we are fairly broad in the categories we include in the series we create. We define our series of interest as "Resurfacing + Maintenance cost per vehicle-mile." This includes all maintenance cost variables and certain capital outlay variables.[80] Vehicle-miles are the estimated number of miles traveled by vehicles on roads in that states. We use all road types in all definitions, but the series looks similar when we exclude local roads. These data are very similar to the series used by Mehrotra et al. (2021). For the FHWA data, we think spending per vehicle-mile is a better measure of cost efficiency, as it implicitly controls for the expected degradation due to heavy road use.

Figure D.8 shows the variation in spending across states for the two sources. There is a striking amount of variation in the FHWA data with Maine, Delaware, and Nebraska spending 4 times per vehicle mile than Mississippi, Georgia, and Alabama. Our series, although still exhibiting variation across states, does not exhibit as much heterogeneity. Importantly, there is very little correlation between the two series. Since we have directly collected resurfacing cost data from the states, this suggests the FHWA data is not a good proxy.

Moreover, it does not seem that costs are higher in areas where roads are rougher in the FHWA data, while our data show a stronger correlation between costs and road quality (Figure D.9). We would expect maintenance costs per lane mile to be higher on rougher, poorer-quality roads, so the lack of correlation with costs in the FHWA data is surprising.

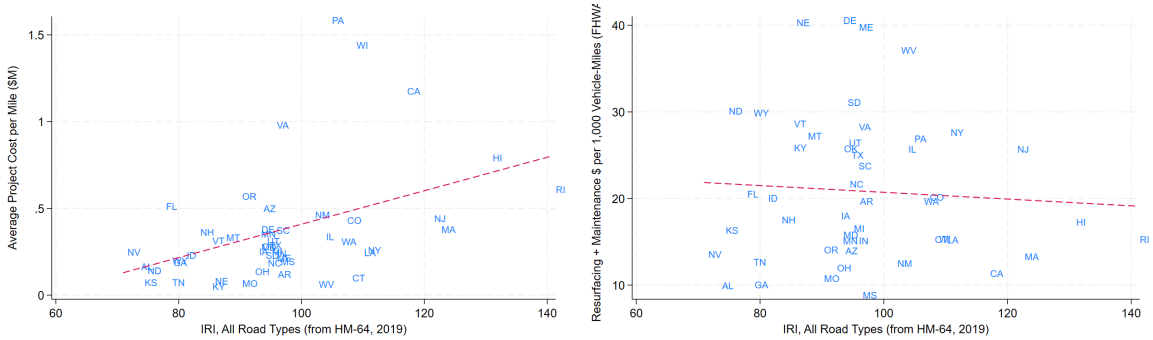
[80] The capital outlay variables are "Relocation," "Reconstruction: Added Capacity," "Reconstruction: No Added Capacity," "Major Widening," "Minor Widening," "Restoration & Rehabilitation," and "Resurfacing."

Figure D.8: Comparison of Cost Data



Notes: This is a scatter plot with cost data collected by the authors on the y-axis and cost data collected by the FHWA on the x-axis. The cost data collected by the authors is for resurfacing projects started in 2018 or 2019, with a length between 1 and 20 miles, on a non-interstate highway. There are 5 such projects per state, and the state average is used for this plot. The FHWA cost data is spending on resurfacing and maintenance per vehicle mile.

Figure D.9: Costs and Road Roughness



(a) Cost per Mile and Roughness

(b) FHWA $ per Vehicle-Mile and Roughness

Notes: The panel on the left shows a scatter plot of state-level resurfacing cost per mile and road roughness (IRI). The cost data collected by the authors is for resurfacing projects started in 2018 or 2019, with a length between 1 and 20 miles, on a non-interstate highway. There are 5 such projects per state, and the state average is used for this plot. The panel on the right shows the same using cost from Highway Statistics (FHWA). To create the cost series we include a subset of capital outlay costs (relocation, reconstruction, major widening, minor widening, restoration, rehabilitation, resurfacing) plus maintenance costs. We use the International Roughness Index (IRI) as the quality measure.

D.3.1 Comparison of FHWA and BidX Data

To further probe the reliability of the Highway Statistics spending data, we compare it to spending totals that we aggregated from BidX, a private-sector service that many state DOTs contract for its construction bidding software. Data from BidX has also recently been used for research purposes (e.g. Bolotnyy and Vasserman, Forthcoming; Kroft et al., 2022). BidX posts winning bids for state DOT construction projects for 38 states. They post descriptions for each project, allowing us to select projects of a similar scope to those we look at in FHWA Highway Statistics.[81]

As a validation exercise, we compare cross-state spending differences in the BidX data with those from Highway Statistics. We first examine Georgia and South Carolina, a pair of states that are similar on observables but have divergent levels of spending per vehicle mile (VM) levels in the Highway Statistics data. In 2018 and 2019, spending per VM is higher in South Carolina in both data sources, but the difference is much larger in Highway Statistics than in BidX.

We repeat the exercise with Georgia and Alabama, two states with very similar spending per VM in Highway Statistics. In the averaged totals across 2014, 2018, and 2019, we find a 15 percent difference between the two states in BidX, whereas the averages in Highway Statistics are virtually identical.

Lastly, we compare New York and North Carolina, which both have high spending per VM in Highway Statistics, to Georgia and Alabama, which both have low spending levels. In 2019, the two datasets disagree: Highway Statistics has the spending per VM significantly higher in NY and NC, whereas BidX has spending per VM significantly higher in Alabama and Georgia. The last comparison also raised a red flag about the internal consistency of the BidX data, as NY has just over 1/3 of the spending per VM as Alabama, which is unlikely to reflect the full universe of spending.

We compare magnitudes of spending in addition to cross-state relative differences. To improve precision, we focus on two categories of spending: resurfacing, rehabilitation, and restoration (3R) and widening/reconstruction. These activities are accounted separately in Highway Statistics and are often grouped together in BidX projects. We choose Georgia for this exercise due to its detailed project descriptions on BidX. In this exercise, the BidX magnitudes are well below those we observe in Highway Statistics.

Overall, it appears that BidX does not typically include the universe of spending laid out in Highway Statistics, and that the degree of the coverage gap in BidX data varies widely by state.

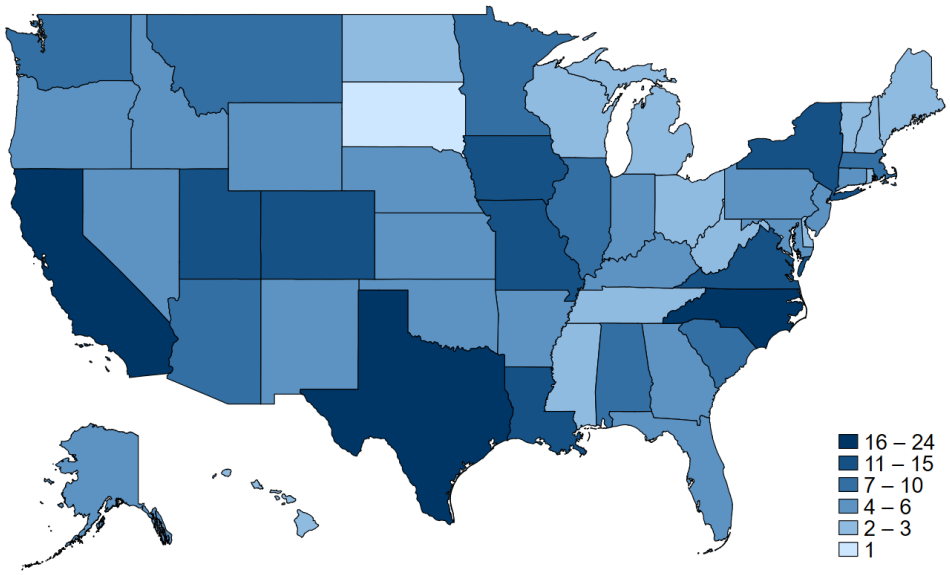
[81] The following keywords are indicative of the projects we are looking for: "resurface," "rehabilitation," "widening," in addition to "mill," "surface," "CMRB." We focused on states that had the most detailed descriptions.

E Survey Descriptives

We note in the text that the largest difference between the response of the contractors and the procurement officials is in whether the state publishes the identity of bidders. It may be that the state publishes the identity of "packet holders," i.e. firms that purchase the project plans, which contractors infer to be the set of bidders they will face even if the DOT is not technically publishing a list of bidders.[82] It may also be that in some markets the bidders know all the potential competitors and can easily infer the identity of the other bidders, even when that information is not shared by the DOT.

We find variation in the length of the stages of the procurement process, highlighted in Figure E.5(a) and (b). For example, states report taking anywhere between 5 days and 3 months between awarding the contract and having the contractor actually sign the contract. The average time between award and signing is roughly one month, but the standard deviation is 22 days. Then, after signing, it can take another 2 months to start construction. Here the average is just under a month, and a standard deviation is 18 days. At each step of the process, increasing the amount of time between the bid letting and the actual construction will increase uncertainty in costs and contractor capacity. The contractors report an even higher number of days in each category.

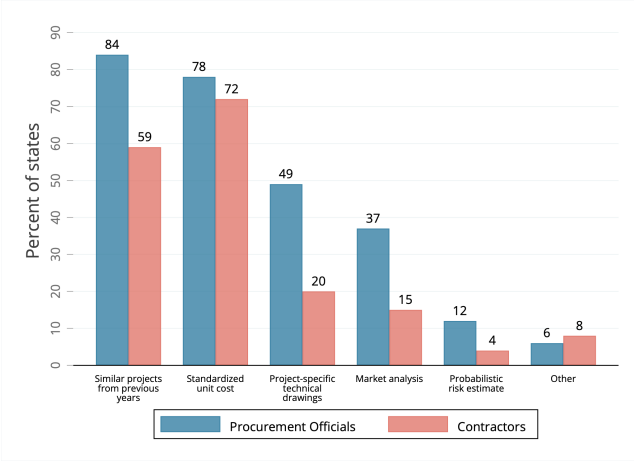
Figure E.2: Survey Respondents by State



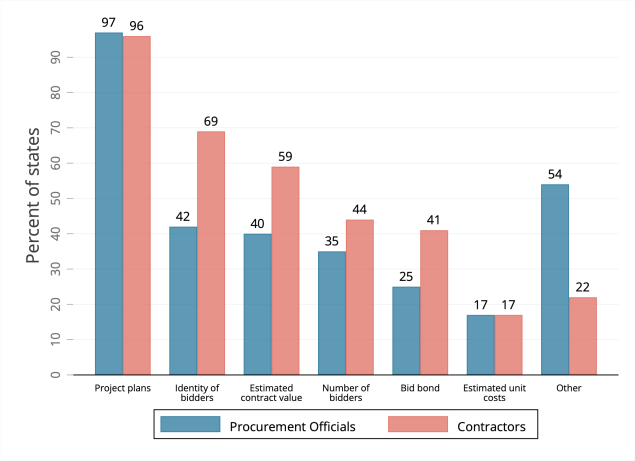
Notes: The map displays the total number of survey respondents by state. This includes both procurement officials and contractors. Contractors are classified according to their primary state.

[82] We do not observe the purchasers of plans in the data so we do not know how often firms purchase the project plans and do not bid.

Figure E.1: Project Planning and Bid Letting



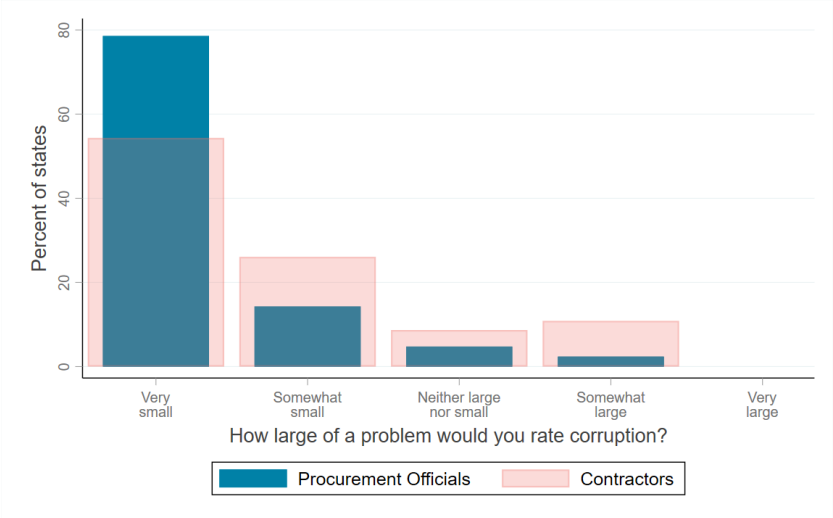
(a) Estimating Contract Costs



(b) Information Published to Bidders

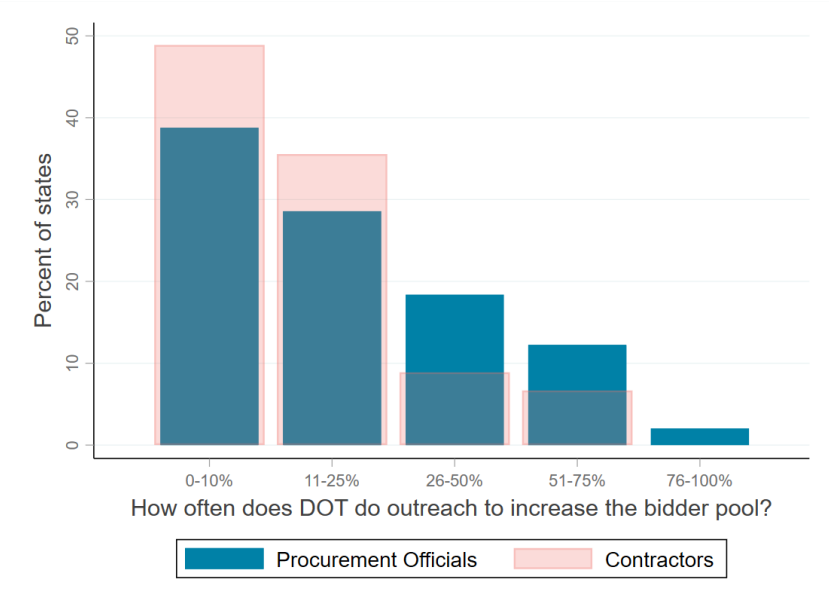
Notes: Author survey. Respondents are directed to select all answers that apply. Data collected by authors, and aggregated to the state level. Survey available in Appendix I.

Figure E.3: Corruption



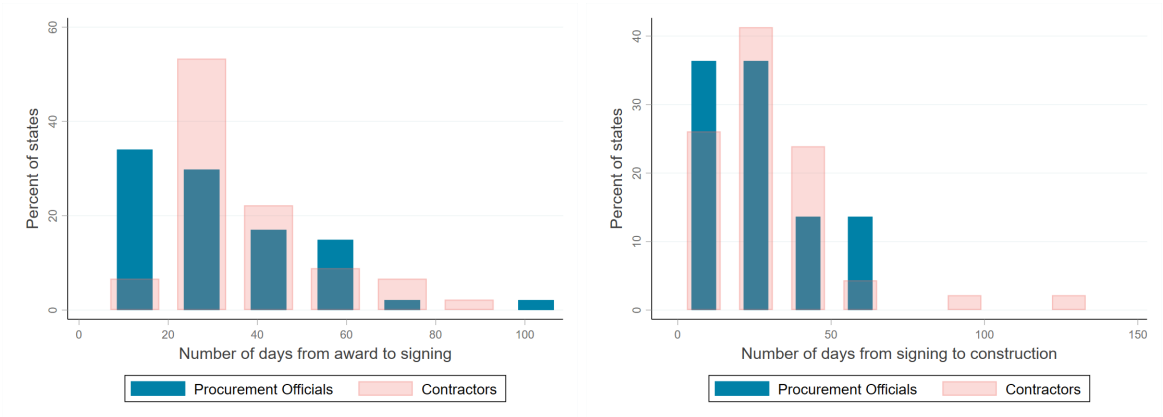
Notes: Author survey. Data aggregated to the state level. Survey available in Appendix I.

Figure E.4: Bidder Outreach



Notes: Author survey. Data aggregated to the state level. Survey available in Appendix I.

Figure E.5: Variation in Timing Across States

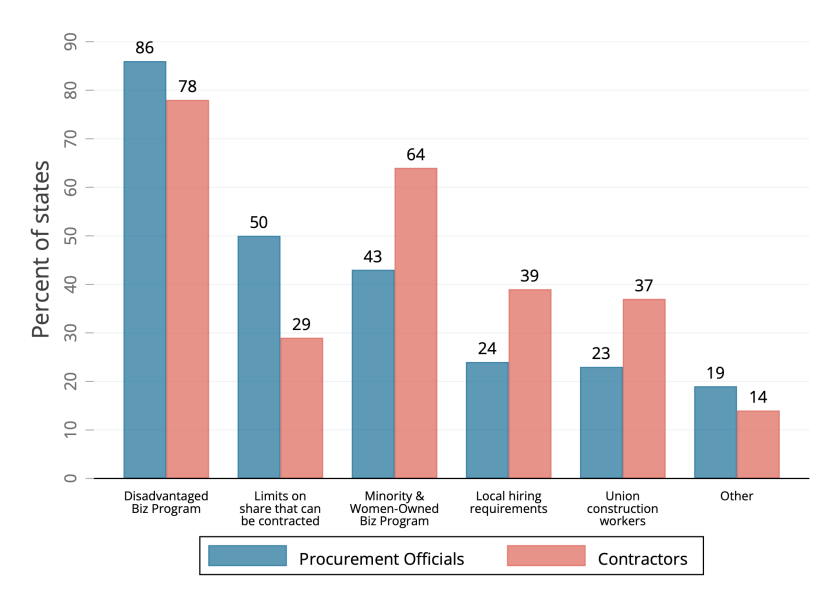


(a) Award to Signing

(b) Signing to Construction

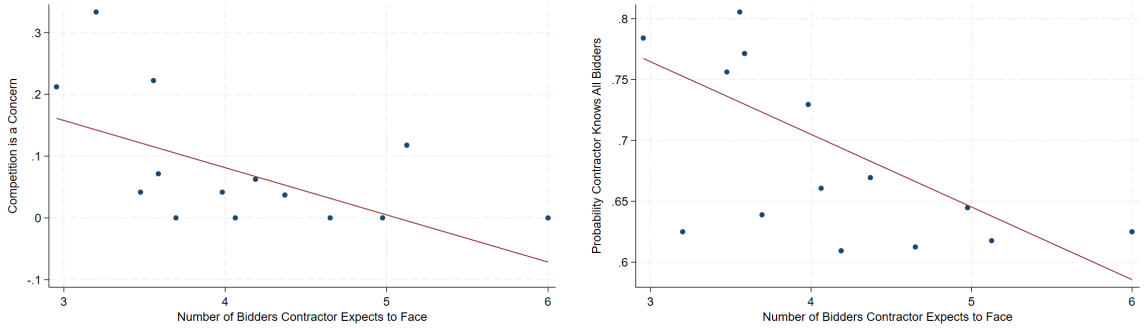
Notes: Author survey. Panels (a) and (b) ask the number of days from contract award to signing and contract signing to the start of construction. Data aggregated to the state level. Survey available in Appendix I.

Figure E.6: Labor and Subcontracting Requirements that Increase Costs



Notes: Author survey. Data aggregated to the state level. Survey available in Appendix I.

Figure E.7: Competition

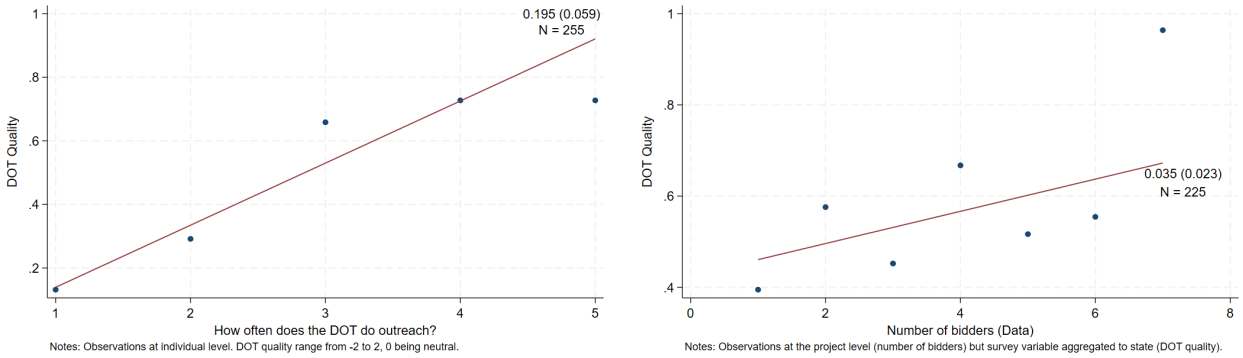


(a) Stated Concerns and # of Bidders

(b) Bidding Behavior

Notes: The panel on the left shows a binned scatter plot with the mention of competition as a concern on the y-axis and the number of bidders a contractor expects to face on the x-axis. This data is from the author survey, and responses are aggregated to the state level by taking the average. The panel on the right shows a binned scatter plot with the probability the contractor knows all of its competitors on the y-axis, and number of bidders on the x-axis.

Figure E.8: DOT Quality and Competition



(a) DOT Quality and Outreach

(b) DOT Quality and Number of Bidders

Notes: The panel on the left shows a binned scatter plot with the DOT quality on the y-axis and the frequency of DOT bidder outreach on the x-axis. This data is from the author survey, and responses are reported at the individual level. The panel on the right shows a binned scatter plot with the DOT quality on the y-axis, and number of bidders from the project-level cost data on the x-axis. Here, the data is aggregated to the state level.

Table E.1: Competition from the point of view of the contractor

Which of the following best describes your experience regarding other companies' bids?	
I can usually predict exactly which firms will bid on a project.	25.2%
I know all the firms that are capable of bidding, but not which ones will actually bid.	22.4%
I know many of the firms that might bid, but sometimes there are surprise bidders.	46.7%
There are often firms bidding that I do not know/expect.	5.7%

Notes: Author Survey. This is the distribution of responses to the survey question "Which of the following best describes your experience regarding other companies' bids?" The question was only asked to the contractors.

Figure E.9: Word Cloud from Free Response on Cost Drivers



Notes: The figure shows the frequency of bigrams in responses to a free response question on cost drivers of highway construction (Question 1 in Appendix I). A bigram is a pair of words used together. Responses are cleaned prior to determining the frequency of bigrams. This is done by removing "stop words" (words such as "the" or "are"), standardizing words, and removing words that are not informative. Text cleaning follows Liscow and Pershing (2022). Responses from both procurement officials and contractors are used.

Table E.2: Key Words for Word Cloud Categories

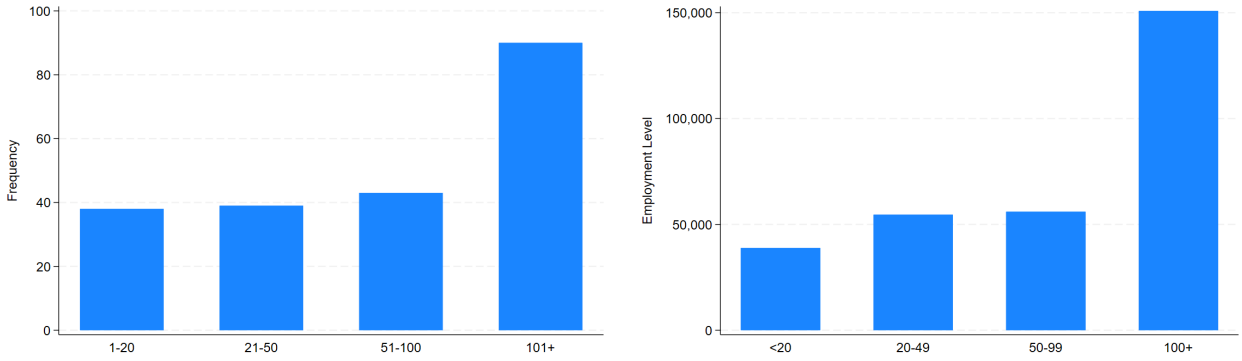
Category	List of Phrases
Materials and Labor	price, wage, material, labor, davis bacon, fuel, asphalt, cement, market condition, supply chain, equipment
Competition	bid, available/availability (without material), dbe, competition, subcontract, limit contract, advertise, wbe
Project Plans and Scope	plan, change, poor, detail, document, specification, scope, design, error, consult
Bureaucracy and Red Tape	paper, certify, red tape, overhead, bureaucrat, admin, require, federal, buy america
Risk and Complexity	risk, insurance, uncertainty, complex, night, traffic, utility(ies), right way

E.1 Contractor Characteristics

In the contractor survey we ask about the identity and characteristics of the firm: number of employees, number of years in business, and number of contracts with the state DOT. We note that the sample of contractors looks similar to the distribution of contracting firms in the U.S. by employment (Figure E.10).

We analyze whether firm characteristics correlate with certain responses to questions. A handful of interesting patterns emerge. First, respondents from larger and more experienced firms are less likely to say that that corruption occurs or is a problem. These characteristics all correlate with lower values assigned to the question, "How large of a problem would you rate corruption;" the result is statistically significant for number of years in business and number of contracts. Second, respondents from larger (in terms of employees and contracts) and more experienced firms are also significantly more likely to select "planning on agency side" as a source of cost overrun. Third, respondents from firms with more years in business expect more firms to bid on projects, perhaps suggesting that the number of bidders has decreased throughout time. This is directly related to the procurement officials responses about the lack of competition.

Figure E.10: Size Distribution of Contracting Firms



(a) Our Survey (b) 2021 QCEW

Notes: The panel on the left shows the distribution of contractor responses to our survey question that inquires about firm size. The question asks the respondent to report the number of employees at the respondent's firm. The respondent is given four options to answer. Those options are displayed on the x-axis. The panel on the right plots the distribution of highway, street, and bridge construction (NAICS 237310) workers by firm size, using data from the 2021 Q1 QCEW. The QCEW reports aggregate data based on the firm size bins that we use for the x-axis. We do not have more granular data from the QCEW to match the size bins used in our survey.

E.2 Data Integrity

To address potential concerns on survey response quality, we perform additional cleaning of survey responses and repeat our main analysis (without Romano-Wolf multiple hypothesis correction). First, we drop individual respondents if they take less than 10 minutes to complete the survey. If respondents rush to finish the survey, they may not be thinking critically about our questions and provide inaccurate answers. Second, we drop individual respondents if they are a contractor and operate in more than five states. If contractors operate in more than five states, we are worried they could confuse procurement processes between states. This would lead to a situation in which a contractor provides information on procurement practices in State X, and we attribute those procurement practices to State Y. For our final response cleaning method, we drop individual respondents if they take less than 10 minutes to complete the survey or if they are a contractor and operate in more than five states. Results using these additional cleaning methods are not substantially different from our main results.

F Additional Observables

F.1 Weather

We collect data on several observable characteristics of states that may be linked to elevated road maintenance costs. The first set is environmental variables, which we download from the NOAA Centers for Environmental Information and average across the years 2000-2019: winter low temperatures, summer high temperatures, and precipitation levels. The first two variables are designed to capture the prevalence of extreme cold or heat, both of which of which cause asphalt deterioration. Precipitation also causes roads to deteriorate more quickly. The NOAA does not have state-level data for snowfall, so to proxy for snowfall levels, we multiply average precipitation by the inverse of average winter low temperature.

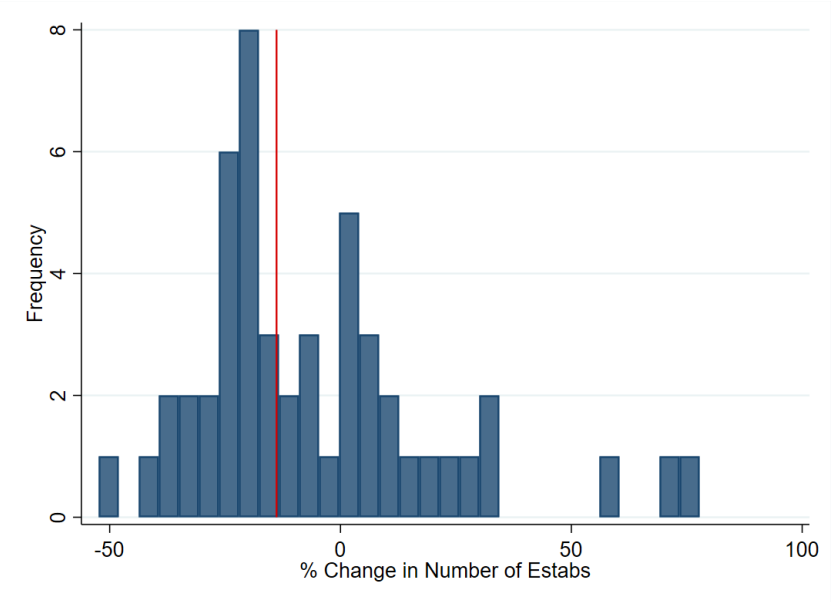
F.2 Market Structure

We take data from the Economic Census for Construction in 2007, 2012, and 2017. This dataset provides state-level employment, payroll, revenues, and cost for all construction industries, including "Highway, Street, and Bridge Construction" (NAICS 23730). We use this data to create state-level variables on labor costs (construction worker payroll/employment), number of establishments, and establishment size (employees per establishment).

Figure F.1 shows how the landscape for highway construction has changed in the 10 years between 2007 and 2017 (we use these years because of the availability of the Economic Census). The majority of states experienced a decrease in the number of establishments in this industry.

In order to study the role of the subcontractor market we collect data from publicly available DBE directories. This gives us the name, address, and NAICS industry code for every firm registered with the state DOT as a DBE. We match the zip codes to commuting zones in order to create a commuting zone measure. This complements our data on DBE goals, which is the percentage of the project that should be completed by a DBE-registered firm, and is a project-specific variable that we collect from the project plans.

Figure F.1: Changes in Highway Construction Establishments: 2007-2017



Notes: The figure shows the change in the number of highway construction establishments in each state, with the vertical line displaying the value of the median state. Data on establishment counts are from US Census Bureau (2007,2012,2017), and we subset to the "Highway, Bridge, and Street Construction" industry (NAICS 2373).

F.3 Public Sector Employment

We have data from the Annual Survey of Public Employment and Payroll (ASPEP), which is produced by the Census Bureau. This includes statistics on the number of state and local government civilian employees and their payrolls in March. We take employment for the "Highways" category in each state as our proxy for DOT employment, normalized by the vehicle-miles in that state.

F.4 Bid Proposal Page Length Data

We primarily used state transportation bidding websites to gather bid proposal documents. We focused on documents contractors were required to fill out and submit as part of their bid proposal. This typically looked like a bid packet PDF which contained project information, specifications, bill of quantities, cost breakdown, company qualifications, and compliance information. We omit highway drawings, addendum documents, or other short form documents.

For the states that use BidX, most states publish a simplified file which contractors fill out using American Association of State Highway and Transportation Officials (AASHTO) software called AASHTOWare. Contractors can use the software and fill out costs and other information as necessary. We took these files and printed them out as PDFs, then measured the page length.

Finally, we gathered a few example bid documents online for states who did not publish bid

documents through their state transportation agency or BidX. We followed a similar approach outlined above, looking for bid packets that included required documents.

The bid packets that we use are generally taken from specific project listings. Project listings were examined to find state highway resurfacing projects. Then, we selected the first project with an available bid packet. We note that these bid packets do not correspond to the exact projects in our dataset, but instead are intended to measure the general size of a standard bid document in each state.

We could not find accessible bid packets for five states. Additionally, we exclude bid packets from twenty states because of concerns over comparability with the rest of the states. These packets were missing multiple items that are typically included across other states (e.g., project descriptions, contractual provisions, compliance information). In total, we use the bid documents of 25 states in Section 5.2. We believe these 25 states are generally comparable with respect to the items included in the bid packets.

G Survey Correlations: Full Results

Table G.1: Pre-bidding Stage

Variable	β	Unadjusted p-value	Romano-Wolf p-value
What does the agency use to estimate contract value?			
Selected 'Project-specific technical drawings'	0.08	0.29	0.89
Selected 'Similar projects from previous years'	-0.01	0.94	1.00
Selected 'Standardized unit cost'	-0.06	0.45	0.99
Selected 'Market analysis'	-0.03	0.61	1.00
Selected 'Probabilistic risk-based estimating'	-0.10	0.18	0.59
Selected 'Feasibility study'	0.03	0.83	1.00
What does the agency publish before bids are due?			
Selected 'Estimated contract value'	0.18	0.04	0.06
Selected 'Number of bidders'	0.11	0.20	0.67
Selected 'Identity of bidders'	0.10	0.14	0.41
Selected 'Estimated/standard unit costs'	0.05	0.52	1.00
Selected 'Bid bond'	0.04	0.67	1.00
Selected 'Project plans'	-0.06	0.23	0.75
Best Practices (Plans and Unit Costs)	-0.17	0.06	0.10
What are common reasons for disqualification?			
Selected 'Past performance'	0.04	0.68	1.00
Selected 'Insufficient bid bond'	0.05	0.59	1.00
Selected 'Firm has wrong specialty'	-0.01	0.85	1.00
Selected 'Technical error'	-0.07	0.44	0.99
Other factors:			
How often does DOT use consultants to draw up project plans?	0.08	0.28	0.88
How often does DOT do outreach to increase the bidder pool?	-0.18	0.02	0.01
Does environmental review slow project planning?†	-0.06	0.50	1.00
Does environmental review increase costs?†	-0.05	0.64	1.00
How often are bidders disqualified at the prequalification stage?†	-0.02	0.76	1.00
How many firms would you expect to bid on project similar to case study?ˆ	0.17	0.10	0.26
How well can you predict the number and identity of bidders?ˆ	-0.05	0.64	1.00

Notes: Beta Estimates are the correlation coefficients between the survey responses and the project cost for the pre-bidding stage of the procurement process. The dependent variable is log cost per lane-mile. Regressions include controls for project, local, and weather observables (per Column (2) of Table 1). The survey responses from the procurement officials and the contractors are aggregated to a state-level average, unless the question was only asked to one group. Each response variable is normalized to have a mean of zero and standard deviation of one, such that correlations are comparable across questions. Unadjusted p-values are computed using standard errors clustered at the state level. Romano-Wolf p-values are adjusted for multiple hypothesis testing, following Clarke et al. (2020). †question asked to procurement officials only. ˆquestion asked to contractors only.

Table G.2: Bidding and Construction Stage

Variable	β	Unadjusted p-value	Romano-Wolf p-value
Evaluating Bids:			
Does legal framework identify unrealistically low bids?†	0.10	0.26	0.84
How often do you suspect that bidders submit unrealistically low bids to win?†	-0.02	0.87	1.00
Are you ever concerned about your bids being declared mathematically unbalanced?ˆ	-0.01	0.93	1.00
How often are bids declared mathematically unbalanced?†	-0.07	0.51	1.00
What share of mathematically unbalanced bids are rejected?†	0.10	0.33	0.94
How often are bids declared materially unbalanced?†	-0.12	0.15	0.48
What share of materially unbalanced bids are rejected?†	0.01	0.94	1.00
Does DOT provide explanation for exclusion in writing?	-0.02	0.84	1.00
Timing and Permits:			
How many days would pass between award and contract signing?	0.03	0.72	1.00
Does the contractor need to obtain permits before contract signing?	-0.05	0.41	0.99
How many days from signing to construction?	-0.01	0.93	1.00
Does the contractor need to obtain permits before construction?	0.05	0.59	1.00
How often is the construction project delivered by the original deadline?	-0.09	0.32	0.93
How often are projects delivered within the awarded amount?	-0.09	0.19	0.63
Change Orders:			
How many change orders (case study)?	0.17	0.05	0.09
How many change orders (design build)?	0.19	0.10	0.26
Is there a percent of material usage that auto triggers change order?†	0.11	0.29	0.89
Are the results of change orders made publicly available?	-0.03	0.70	1.00
How many days from change order request to amendment?	-0.13	0.16	0.49

Notes: Beta Estimates are the correlation coefficients between the survey responses and the project cost for the bidding and construction stages of the procurement process. The dependent variable is log cost per lane-mile. Regressions include controls for project, local, and weather observables (per Column (2) of Table 1). The survey responses from the procurement officials and the contractors are aggregated to a state-level average, unless the question was only asked to one group. Each response variable is normalized to have a mean of zero and standard deviation of one, such that correlations are comparable across questions. Unadjusted p-values are computed using standard errors clustered at the state level. Romano-Wolf p-values are adjusted for multiple hypothesis testing, following Clarke et al. (2020). †question asked to procurement officials only. ˆquestion asked to contractors only.

Table G.3: Cost Overruns and Delays

Variable	β	Unadjusted p-value	Romano-Wolf p-value
Main reasons for project delays:			
Administrative processes drive delays	0.15	0.06	0.10
Selected 'Capacity of the agency'	-0.05	0.45	0.99
Selected 'Legal challenges by citizens' groups'	0.05	0.51	1.00
Selected 'Capacity of the contractor'	-0.02	0.80	1.00
Selected 'Financial constraints of the contractor'	0.02	0.79	1.00
Selected 'Planning on the agency side'	-0.02	0.87	1.00
Selected 'Change of project scope'	0.07	0.28	0.88
Selected 'Third party delays'	-0.02	0.85	1.00
Selected 'Weather shocks'	-0.00	0.97	1.00
Main reasons for cost overruns:			
Selected 'Burdensome administrative processes'	-0.11	0.19	0.63
Selected 'Capacity of the agency'	-0.08	0.36	0.96
Selected 'Legal challenges by citizens' groups'	-0.06	0.32	0.94
Selected 'Capacity of the contractor'	-0.07	0.30	0.90
Selected 'Financial constraints of the contractor'	0.05	0.36	0.96
Selected 'Planning on the agency side'	-0.15	0.09	0.21
Selected 'Change of project scope'	-0.12	0.25	0.81
Selected 'Third party delays'	-0.08	0.33	0.94
Selected 'Weather shocks'	-0.18	0.02	0.02
Selected 'Market Conditions'	-0.03	0.67	1.00
Labor/Contract requirements that increase cost:			
Selected 'Disadvantaged Business Enterprise Program requirements'	-0.10	0.15	0.45
Subcontracting limits drive costs	0.16	0.01	0.00
Selected 'Local hiring requirements'	-0.02	0.88	1.00
Selected 'Minority and Women Owned Business Enterprise Program'	-0.00	0.96	1.00
Selected 'Union construction workers'	0.06	0.57	1.00

Notes: Beta Estimates are the correlation coefficients between the survey responses and the project cost for the questions about cost overruns, delays, and labor costs. The dependent variable is log cost per lane-mile. Regressions include controls for project, local, and weather observables (per Column (2) of Table 1). The survey responses from the procurement officials and the contractors are aggregated to a state-level average, unless the question was only asked to one group. Each response variable is normalized to have a mean of zero and standard deviation of one, such that correlations are comparable across questions. Unadjusted p-values are computed using standard errors clustered at the state level. Romano-Wolf p-values are adjusted for multiple hypothesis testing, following Clarke et al. (2020). †question asked to procurement officials only. ˆquestion asked to contractors only.

Table G.4: Characteristics and Corruption

Variable	β	Unadjusted p-value	Romano-Wolf p-value
DOT Characteristics			
Consultants drive costs	0.19	0.02	0.01
Staffing at DOT (- Understaffed to + Overstaffed)	0.05	0.56	1.00
How would you rate the quality of the employees at the DOT?	-0.14	0.09	0.21
How long does it take DOT to respond?ˆ	0.06	0.49	1.00
Firm Characteristics			
Engages in research-and-development to lower infrastructure costsˆ	-0.14	0.14	0.43
Corruption:			
How large of a problem would you rate corruption?	-0.02	0.74	1.00
Does corruption drive away bidders?	0.02	0.87	1.00
Does corruption drive up costs?	0.03	0.75	1.00
Aware of 'Bidder collusion' in state	-0.03	0.68	1.00
Aware of 'Unethical contractor behavior' in state	0.14	0.09	0.22
Aware of 'Improper state employee behavior' in state	-0.04	0.57	1.00
Not aware of any corruption in state	-0.15	0.11	0.30

Notes: Beta Estimates are the correlation coefficients between the survey responses and the project cost for the questions about DOT and Contractor characteristics and corruption. The dependent variable is log cost per lane-mile. Regressions include controls for project, local, and weather observables (per Column (2) of Table 1). The survey responses from the procurement officials and the contractors are aggregated to a state-level average, unless the question was only asked to one group. Each response variable is normalized to have a mean of zero and standard deviation of one, such that correlations are comparable across questions. Unadjusted p-values are computed using standard errors clustered at the state level. Romano-Wolf p-values are adjusted for multiple hypothesis testing, following Clarke et al. (2020). †question asked to procurement officials only. ˆquestion asked to contractors only.

Table G.5: Project Costs, Observable Cost Drivers, and Survey Inputs

	Project-Level Log(Cost/Mile)		
	(1)	(2)	(3)
Project Details:			
Complex Dummy	0.818***	0.757**	1.039***
	(0.282)	(0.324)	(0.285)
Lane-Miles	-0.023***	-0.023***	-0.026***
	(0.004)	(0.004)	(0.004)
State Highway Dummy	-0.046	-0.150	0.053
	(0.122)	(0.125)	(0.131)
Local Characteristics:			
Log(Population Density)	0.052	-0.050	0.019
	(0.041)	(0.042)	(0.037)
Log(Wages in Hwy Construction)	0.064	0.263	0.131
	(0.176)	(0.254)	(0.186)
State Characteristics:			
Precipitation	-0.032***	-0.030***	-0.032***
	(0.006)	(0.005)	(0.005)
Winter Low	0.041***	0.044***	0.047***
	(0.010)	(0.003)	(0.011)
Snow Proxy	0.019	-0.008	0.001
	(0.015)	(0.015)	(0.015)
Summer High	-0.039*	0.005	-0.047***
	(0.021)	(0.007)	(0.017)
Roughness Index	0.017***	0.003	0.009***
	(0.005)	(0.003)	(0.003)
Survey Variables	No	All	Figure 6
Observations	250	250	245
R-squared	0.39	0.69	0.48
Adj. R-squared	0.36	0.60	0.44

Notes: This table replicates Table 1 in the main text of the paper, but adds as controls the survey responses. Column (1) replicates Column (3) from Table 1, Column (2) adds all 79 survey variables as controls, and Column (3) uses only the 9 survey variables that we find to be statistically significant.

H Background on Caltrans Engineers

The majority of engineers in our data are "Transportation Engineer (Civil)." This includes 58% of retirements, 83% of resident engineers, and 23% of project managers. Therefore, we take this section to provide additional information on the role of the transportation engineer.

The official "California State Personnel Board Specification" describes the job and the typical tasks for the role (see `https://www.calhr.ca.gov/state-hr-professionals/Pages/3135.aspx`):

> "This is the entry, first working, and journey level of professional engineering work in Caltrans. At the journey level and with registration may be in a responsible charge capacity. Under the direction of a registered engineer, incumbents perform a wide variety of professional engineering work in either an office or field setting; as incumbents progress in experience they will be assigned more difficult work and may function as a lead person over the activities of various engineering and technical personnel; and do other related work. A Transportation Engineer (Civil) performs engineering work involving plans, designs, details and maintenance of transportation systems, in whole or in part, that may include land, rail, freeways, roads, airports, ramps, hydraulics, sanitary facilities, bridges, nonstandard major structures or transportation-related buildings and other structures; makes layouts, assembles specifications; reviews or assists in reviewing project proposals, plans, and specifications prepared by others; acts as resident engineer on small-to medium-sized construction projects; works up special provisions and contract estimates; keeps or assists in keeping the necessary records pertaining to construction progress, job expenditures, budget programs, and work order balances; confers with contractors regarding compliance with plans and quality of work and construction activity; selects and/or uses computer-based processes to compile engineering data, horizontal and vertical alignments and curve computations; develops or assists in the development or maintenance of transportation-related state-of-the-art computer programs and procedures; makes or revises maps, charts and diagrams; uses project management systems to budget personnel and set milestones for transportation projects; makes field investigations of and for laboratory analysis of materials being used in construction transportation and public works research projects; makes controlled tests and checks performance of construction materials, soils, aggregates, cement, asphalt, concrete, and other materials; on construction projects, analyzes and approves or assists in analyzing and approving materials incorporated in bridges, nonstandard major structures or transportation-related buildings; evaluates or assists in evaluating damage for all types of transportation facilities including bridges and other nonstandard major structures; makes in- plant investigations and recommendations about materials, plant design and operations; may use underwater diving equipment to make underwater quality control and structure investigations; performs transportation operational, traffic operations, planning or maintenance engineering tasks; prepares and presents information to the public about all types of transportation engineering matters; tests for and prepares environmental reports, assessment reports of transportation surveys, investigations and analysis statements, and air and water quality reports; assists a registered engineer in performing professional engineering work; may lead other engineering and technical personnel."

The next most common position in our data is the Senior Transportation Engineer. This is a more managerial position, which is clear from the job description:

> "Under general direction, (1) as a first line supervisor to have charge of varied and difficult trans-

> portation engineering work in the field or office involving the supervision of engineers and others engaged in transportation development activities; or (2) in a specialist capacity, to perform other difficult and complex engineering work relating to specialized transportation projects, research studies, planning and operations of transportation systems; or (3) provide technical oversight of consultants or local agency staff performing engineering work related to the development of State transportation projects; and to do other related work."

The typical tasks of the Senior Transportation Engineer include:[83]

> "In a district, plans, assigns, and checks work, gives instructions and assistance, maintains discipline, makes decisions and handles difficult technical and administrative problems in connection with directing the work of engineers and others; provides technical oversight of consultants performing engineering work under contract with the Department; manages engineering contracts between the Department and private engineering firms; provides technical oversight of consultants or local agency staff performing engineering work related to the development of State transportation projects funded by local agencies or private entities; supervises the preparation of designs, plans, quantities, specifications and construction drawings for transportation projects; as a project manager, ensures that assigned projects are completed within scope, cost, schedule, budgeted resources, and departmental standards and practices; makes original investigations in connection with the preparation of unusual or complicated designs; acts as a resident engineer on large, complex or equivalent multiple construction projects; supervises the preparation of planning and traffic studies and investigations, including transportation surveys, road inventories, and traffic accident investigations; supervises the preparation of progress and final estimates; supervises the preparation of investigations and economic studies of alternative transportation facility routing; supervises transportation operational or maintenance engineering units; supervises the preparation of environmental reports, assessment reports of surveys and investigations, investigation of hazardous materials and appropriate mitigation and other comprehensive reports and investigations; supervises the preparation of transportation and encroachment permits; develops personnel requirements and monitors use of personnel in meeting engineering project and operations schedules; presents information to the public on transportation engineering matters; represents the Department of Transportation at meetings; prepares correspondence and reports."

There are many potential tasks assigned to a Transportation Engineer. We only observe a sliver of the engineer's job: we know when they are assigned as resident engineer or project manager for a project in our data. However, the majority of the tasks, though direct inputs into project completion, will not be observable to us.

[83] The source for both the description and the typical tasks is `https://www.calhr.ca.gov/state-hr-professionals/Pages/3161.aspx`.

H.1 Engineer Assignment

A concern for our analysis of the role of individual engineers' experience is the endogenous assignment of engineers to projects. If the less experienced engineers are assigned to more complicated projects, this would bias our results upwards, and the positive relationship would be due to the assignment mechanism, not the effect of experience. However, all of the institutional details suggest the opposite– the more experienced and qualified engineers are assigned to more complicated projects.

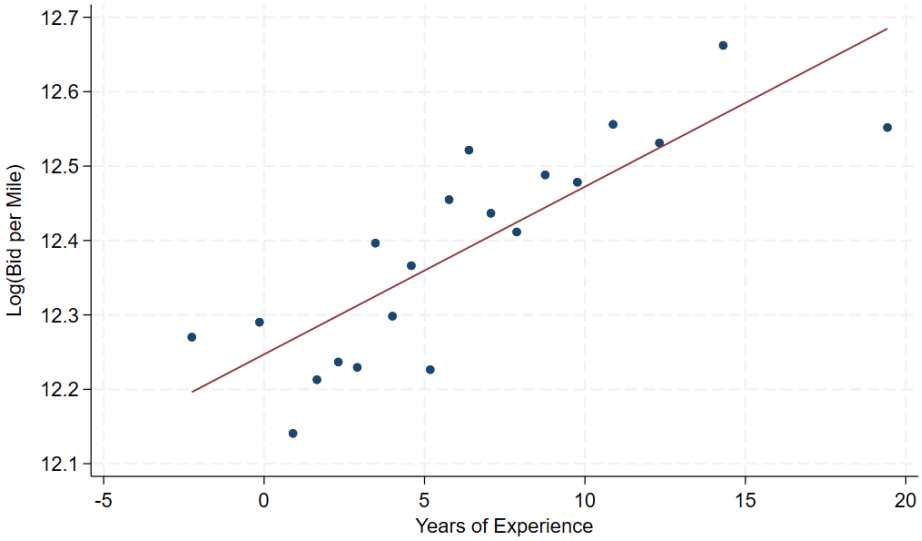
The Caltrans Construction Manual has the following guidelines for assigning resident engineers.[84]

> "Selecting a person to act as resident engineer is dependent upon the following: The work's magnitude and complexity, The type of work, The degree of independent control and direction to be exercised, Pursuit or completion of the Caltrans Resident Engineer Certificate Program. Only the person best qualified for a specific project should be selected as the resident engineer. The civil service classification of a resident engineer is related to the project's size and complexity as well as to the staff size required to properly administer the assigned contract or contracts. Normally, the person selected as resident engineer will be a licensed engineer at the transportation engineer level. On complex projects (or a group of projects) that require a large staff to monitor the contractor's operations, a senior level engineer may be necessary. Complexity, rather than monetary value, governs the assignment of resident engineers."

Figure H.1 shows the relationship between engineer years on the job and the size of the project they are assigned to. The figure shows that more experienced engineers are assigned to "larger" projects, where project size is measured by the winning bid. We take engineer years on the job from the construction data, where we see resident engineer assignment from 1970-2023. Generally, we only use this data starting in 2000 because that is when we start to observe costs. However, we can use the older projects to identify the first year we observe a resident engineer in the data, and then calculate their experience off of that first observation. We only have this for the resident engineers, not the project managers.

[84] The manual is available at `/https://dot.ca.gov/-/media/dot-media/programs/construction/documents/policies-procedures-publications/construction-manual/sec1-1.pdf`.

Figure H.1: Resident Engineer Assignment



Notes: The figure shows the relationship between engineer experience and the total winning bid per mile. The figure shows that more experienced engineers are assigned to "larger" projects, where large is measured by the winning bid. We use this as a proxy for project complexity—projects with higher bids per mile should be more difficult and complex to complete. The binned scatter plot is residualized, controlling for County, Year, and Route. Engineer experience is measured in years, using the first year we observe them in the construction data as a resident engineer as the starting year.

Finally, we had an extended conversation with a senior engineer at the division of construction at Caltrans in order to understand the institutional details. Our contact formally worked as a staff transportation engineer, and then as a senior transportation engineer and project manager, before moving to upper management. He described the assignment of project managers to projects as follows: "Managers do not want to assign inexperienced Project Managers to complex projects." He described that the division wants projects to succeed, therefore if they can predict a project will be difficult they will give it to someone with more experience and/or capability. He also explained that how each district assigns projects can vary, some use geography (i.e. engineers are split between counties), some use the route, some use the project type. We control for all 3 variables in our regressions, in order to try to capture variation in engineer quality and experience *within* assignment mechanism.

H.2 Measuring Engineer "Quality"

We collect the salary and job title for each engineer and project manager in our dataset from 2011-2018. We are able to find salary information for 98% of the engineer-year pairs via "Transparent California." "Transparent California" is a non-profit that collects information on public employee pay and pensions via public records requests. The salary data on their portal includes "Regular Pay," "Other Pay," "Overtime," and "Benefits." We create a compensation measure that is the sum of "Regular Pay" and "Benefits." We inflation adjust this measure to 2018 dollars.

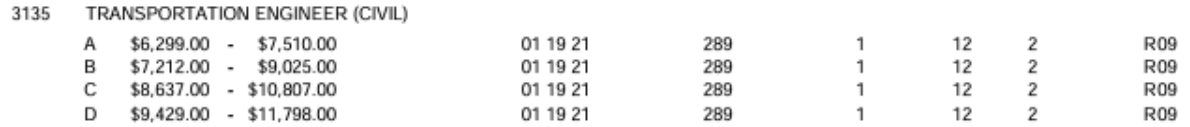
Table H.1 shows compensation by job title. The majority of engineers are Staff Transportation Engineers (i.e. have the job title "Transportation Engineer (Civil)"). These are also the majority of engineers that are assigned as resident engineers in our data (% RE in the table). Project managers (% PM) are more likely to be senior transportation engineers, but still, 23% are staff transportation engineers. Table H.1 shows that pay progresses with seniority (i.e. Seniors make more than Staff engineers). However, there is still significant dispersion within job title. This is due to variation in experience and training within position, as we describe in the main text. This is the variation that we will exploit to create a measure of engineer "quality."

Table H.1: Compensation and Project Position by Job Title

	Salary and Benefits ($2018)				Percent of (%)		
Job Title	Mean	Median	SD	N	Total	RE	PM
Electrical Engineer							
Staff	142,793	149,321	21,951	89	2.9	3.1	0.5
Senior	148,880	156,483	29,256	11	0.4	0.5	0.1
Bridge Engineer							
Senior	157,658	169,849	28,710	21	0.7	0.2	4.6
Transportation Engineer							
Staff	138,869	147,279	24,891	1,930	62.7	82.7	23.1
Associate	152,906	159,747	18,985	29	0.9	1.1	0.4
Senior	159,192	166,646	26,805	780	25.3	8.5	58.2
Principal/Supervising	173,320	179,352	29,545	62	2.0	0.2	5.9
Landscape Architect							
Staff	138,275	145,306	23,257	67	2.2	3.0	0.1
Senior	163,353	172,752	25,974	16	0.5	0.5	1.1
Planner/Surveyor/Other							
Staff	83,144	78,290	32,629	27	0.9	0.2	1.8
Senior	114,595	115,395	33,511	48	1.6	0.0	4.3
Total	144,366	150,271	28,220	3,080			

Notes: This table shows the mean, median, and standard deviation for compensation (salary plus benefits) for each job title. The observation is at the engineer-year, and we match the engineer to job title and salary by name, using "Transparent California." We then report the percent of resident engineers and project managers that have each job title.

Figure H.2: State of California Pay Scale for Transportation Engineer (Civil)



3135	TRANSPORTATION ENGINEER (CIVIL)							
	A	$6,299.00 - $7,510.00	01 19 21	289	1	12	2	R09
	B	$7,212.00 - $9,025.00	01 19 21	289	1	12	2	R09
	C	$8,637.00 - $10,807.00	01 19 21	289	1	12	2	R09
	D	$9,429.00 - $11,798.00	01 19 21	289	1	12	2	R09

Notes: This is the pay scale for Transportation Engineer (Civil) in 2025. The source is `https://www.calhr.ca.gov/Pay20Scales20Library/PS_Sec_15.pdf`.

Figure H.2 shows a screenshot of the pay scale for transportation engineers (associate, senior, etc. have a separate pay scale).[85] This is for the year 2025, and reports salaries at the monthly level. You can see that there are multiple levels within the Transportation Engineer category: the lowest monthly salary is about $6,300, while the highest is almost double that, at $11,800. Engineers are able to move within and across ranges with experience. They are only able to reach range D after becoming a licensed professional engineer (PE) with the state. The pay scale document also shows that Associate Transportation Engineer pay range is the same as the highest (range D) Staff Transportation Engineer. For this reason, and because there are so few Associate Transportation Engineers in the data, we relabel them as Staff Transportation Engineer for the purposes of further analysis.

We use the compensation data to create a measure of quality. We view our "quality" measure as capturing higher compensation due to both experience and quality of the employee. We know that salary progresses as a function of both of these underlying variables, which we do not observe independently. Table H.2 shows the result of a regression of year dummies on the total compensation of the engineers in the sample. Compensation is inflation adjusted to 2018 dollars, and we include a dummy for observations where we are missing benefits data, which is entirely concentrated in 2011 and 2012. The first column uses the most common job title ("Transportation Engineer (Civil)"). The second column uses any employee in the "Transportation Engineer" title, so this includes Senior and Supervising engineers. The third column uses the full sample, but does not control for job title. The fourth column also uses the full sample, but includes the job title dummies. Year and job title dummies explain about 80% of the variation in compensation. The residual is what we will attribute to "quality."

Figure H.3 shows the residual of the compensation regression in Column (4). The distribution is shown separately for the staff-level and senior-level employees. We focus on the quality residual within job title, because we see job title explains much of the assignment to project type and/or to the project position (resident engineer vs project manager). If senior engineers are more likely to

[85] The source is `https://www.calhr.ca.gov/Pay20Scales20Library/PS_Sec_15.pdf`.

Table H.2: Compensation Regressions

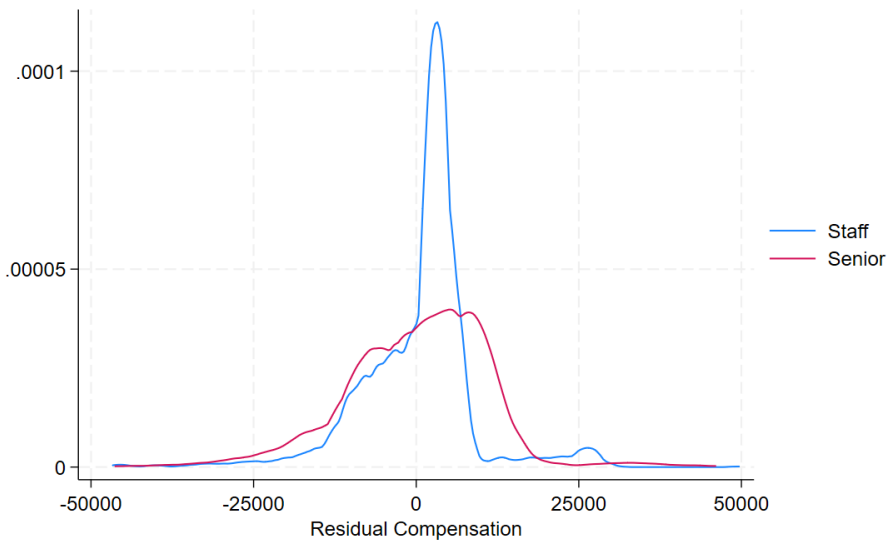
	Compensation = Salary + Benefits ($2018)			
	(1)	(2)	(3)	(4)
Year (Base is 2011)				
2012	2,499.82***	2,382.23***	3,632.40***	2,580.73***
	(793.16)	(638.47)	(919.91)	(644.24)
2013	-6,385.71	-1,899.94	12,415.03	5,891.97
	(7,179.47)	(7,592.93)	(15,257.86)	(8,027.01)
2014	-1,176.36	4,452.76	19,007.96	12,294.21+
	(7,197.98)	(7,614.34)	(15,305.26)	(8,051.36)
2015	4,237.74	10,212.08	23,325.04+	17,763.86**
	(7,185.79)	(7,613.35)	(15,309.99)	(8,061.53)
2016	10,492.17+	16,795.75**	30,033.03**	24,444.04***
	(7,182.41)	(7,618.18)	(15,309.14)	(8,055.13)
2017	12,687.35*	17,897.94**	31,616.80**	25,911.87***
	(7,216.46)	(7,636.09)	(15,311.73)	(8,075.80)
2018	13,880.50*	19,664.93**	33,192.08**	27,402.97***
	(7,258.78)	(7,653.44)	(15,322.67)	(8,085.23)
No Benefits Data	-43,269.02***	-39,712.40***	-26,767.96*	-31,622.35***
	(7,138.76)	(7,582.43)	(15,242.48)	(8,044.53)
Job Title (Base is Staff Transport. Eng.)				
Senior Transport. Engineer		20,134.16***		20,164.47***
		(474.77)		(477.27)
Supervising Transport. Engineer		34,045.00***		34,180.08***
		(1,372.75)		(1,376.58)
Staff Electrical Engineer				2,893.70***
				(836.12)
Senior Electrical Engineer				15,252.48***
				(3,215.34)
Senior Bridge Engineer				20,509.01***
				(2,120.90)
Staff Landscape Architect				-242.92
				(1,019.75)
Senior Landscape Architect				19,320.24***
				(1,709.24)
Staff Planner/Surveyor				-50,801.81***
				(4,669.85)
Senior Planner/Surveyor				-21,619.24***
				(4,327.31)
Constant	145,369.33***	140,333.37***	132,045.24***	132,461.57***
	(7,164.13)	(7,598.36)	(15,283.82)	(8,040.24)
Sample	Staff TE	All TE	All	All
R-squared	0.78	0.83	0.65	0.82
Observations	1,959	2,801	3,080	3,080

Notes: This table shows a regression of compensation (salary plus benefits) on year dummies, a dummy for missing benefit data, and job title dummies. Compensation is inflated adjusted to 2018 dollars. The first column includes only staff Transportation Engineers, the second column includes all transportation engineers, and columns (3) and (4) include all individuals that we are able to match to salary data. The results do not meaningfully change when we include district fixed effects.

be in the project manager position, the relevant experience is their experience as a project manager, dealing with multiple phases and communicating with multiple stakeholders—not just their time as a staff engineer drawing up plans or in the construction team.

In Table H.3, we use the residual to predict the number of years of experience of our resident engineers. Here, we take engineer years on the job from the construction data, where we see resident engineer assignment from 1970-2023, and therefore use the first year we see an employee as a resident engineer as their starting year. This is not a perfect measure. First, in only measures years of experience, not any other quality inputs. Second, as we described in the background, there are many jobs an employee can do as an engineer at Caltrans. There are many resident engineers we only observe a few times in the data; this is not because they only work for a couple of years at Caltrans, but it is just that they are doing other tasks besides the Resident Engineer task. Given those caveats, Table H.3 shows that the compensation residual is strongly positively correlated with the number of years of experience and the number of projects completed for a resident engineer. However the R-squared is relatively low. Measurement error in the years of experience is attenuated when we restrict the sample to engineers we see at least 5 (column (4)) or 10 times (Column (5)) in the project-level data. The R-squared increases with these restrictions.

Figure H.3: Residual Compensation



Notes: This figure shows the distribution of residual compensation. Compensation is predicted for each Caltrans employee, using the results in Column (4) of Table H.2. We show the distribution separately for staff and senior positions.

Table H.3: Compensation Residual vs. Years of Experience

	Years of Experience				
	(1)	(2)	(3)	(4)	(5)
"Quality" Residual	0.774***	0.856***	0.809***	0.615***	0.530***
	(0.149)	(0.148)	(0.148)	(0.163)	(0.183)
R-squared	0.06	0.10	0.11	0.16	0.19
	Number of Projects				
	(1)	(2)	(3)	(4)	(5)
"Quality" Residual	1.280***	1.428***	1.364***	1.212***	1.216***
	(0.308)	(0.312)	(0.311)	(0.358)	(0.435)
R-squared	0.03	0.10	0.11	0.14	0.17
Job Title FE	×	×	×	×	×
District FE		×	×	×	×
Year FE			×	×	×
Project Cut-off				5	10
Observations	2,106	2,106	2,106	1,810	1,369

Notes: We use the residual from Column (4), Table H.2 to predict the number of years of experience of our resident engineers. Here, we take engineer years on the job from the construction data, where we see resident engineer assignment from 1970-2023. We use the first year we see an employee as a resident engineer as their starting year. We include job title fixed effects in each specification, district fixed effects in columns (2) - (5) and year fixed effects in columns (4) - (5). In Column (4), we restrict to engineers that we observe attached to at least 5 projects in the construction project data, and in Column (5), the restriction is 10 projects.

H.3 Project Types

We use as much of the data from Caltrans as possible, which means we do not only study resurfacing projects. Therefore, we need to control for the project type in order to control for differences in costs and complexities between projects. In order to do this we use the short project descriptions that are supplied in the project-level data. These descriptions will include something along the lines of "RESURFACE ROADWAY" or "COLD PLANE AC PAVEMENT PLACE HMA" or "TREAT BRIDGE DECK W METHACRYLATE."

We classify each project by the verb and the noun in the project description. We take 6 verb categories: build, install, planting/irrigation, rehabilitation, resurfacing, widen. Table H.4 shows the exact verbs that are considered in each category. We take 4 categories of nouns: bridge, road, auxiliary road (this would include highway medians, guardrails, walls, etc.), and other. Taking these noun and verb categories together, we get 16 project types (not every combination exists in the data). Table H.5 shows the distribution of cost per mile for the types, and the number of observations, for the sample of projects we use in the experience regressions.

Table H.4: Project Types: Verb Categories

Category	Words
Build	build, construct, rebuild, reconstruct
Install	add, apply, install, place
Planting/Irrigation	clear, control, environment, excavate, fell, irrigation, landscape, mitigation, planting, revegetation
Rehabilitation	correct, enhance, fix, improve, modify, rehabilitate, reinforce, relocate, remodel, remove, repair, replace, restore, retrofit, revise, stabilize, update, upgrade
Resurfacing	digout, grade, grind, groove, microsurfacing, mill overlay, pave, paving, regrade, resurface, seal, surfacing
Widen	channelize, convert, expand, extend, realign, widen

Table H.5: Cost per Mile ($M) by Project Type

Project Type	Mean	Median	SD	N
build:bridge	19.0	7.4	28.6	15
build:other	20.0	0.9	73.8	75
build:road	25.3	6.2	94.6	52
build:road, aux.	10.1	1.3	35.1	171
install:other	1.5	0.2	3.5	104
install:road, aux.	1.5	0.4	4.7	131
planting/irrigation: other	2.1	0.5	5.5	247
rehabilitation:bridge	6.5	1.0	16.0	171
rehabilitation:other	2.6	0.5	7.8	161
rehabilitation:road	2.7	1.0	4.4	160
rehabilitation:road, aux.	4.6	1.3	10.1	102
resurfacing:bridge	3.0	0.9	4.3	6
resurfacing:road	3.3	0.8	15.7	144
resurfacing:road, aux.	0.8	0.7	0.6	30
widen:bridge	22.6	10.2	68.0	29
widen:road	11.6	4.5	25.5	135
Total	6.27	0.92	29.19	1,733

Notes: This table presents the mean, median and standard deviation of cost per mile by project type. The types are defined by the authors, using the short project descriptions in the data. We use these project types as controls in the experience regressions.

H.4 Retirements

We construct a district-year panel of Caltrans projects and retirements. The non-profit "Transparent California" shared Caltrans' pension records for 2012-2023. In these records, we observe the retirement year, district, and job title at retirement for all Caltrans employees who were still drawing a pension (i.e., living) as of the record year. As such, we have the near-universe of pension records for retirements in the 2010s, and what we believe to be the vast majority of records for the 2000s.[86] In addition, employment records for Caltrans are available for the years 2011-2023. These records track salary and job title, but do not track the district in which employees work.

We select the pension records on the job title "Transportation Engineer." We know that this covers the vast majority of engineers in our sample of project managers and resident engineers, and we know from the institutional details that this is the majority of engineers at Caltrans. Appendix Table H.6 shows the distribution of retirements, by title. The staff engineers (Transportation Engineer (Civil)) retire with 26 years of experience, on average.[87] Then, there are more senior engineers (associate, senior, principal, and supervising transportation engineers). These employees have slightly more experience at retirement (31 years, on average).

Table H.6: Retirements by Job Title

Job Title	Obs.	Avg. Years of Service	Avg Year of Retirement
ASSOCIATE TRANSPORTATION ENGINEER	258	31.9	2007.7
PRINCIPAL TRANSPORTATION ENGINEER	19	31.1	2013.3
SENIOR TRANSPORTATION ENGINEER	403	30.0	2011.4
SUPERVISING TRANSPORTATION ENGINEER	97	34.0	2011.1
TRANSPORTATION ENGINEER (CIVIL)	1,426	26.1	2010.5
TRANSPORTATION ENGINEER (ELECTRICAL)	110	24.3	2012.2
Total:	2,313	27.7	2010.5

Notes: Table H.6 shows the distribution of retirements in the data, by job title. Retirement records are from "Transparent California." We study retirements between 2000-2018.

We also have the universe of project-level cost data from the Caltrans construction division, as we describe in the main text. We exclude some projects that do not follow typical construction or maintenance timelines, such as planting and irrigation contracts that have a fixed duration. Otherwise, we use all Caltrans projects for which an award date is available. We restrict to projects that were awarded in 2000-2018 to ensure that all projects are completed, and to minimize the effect of the

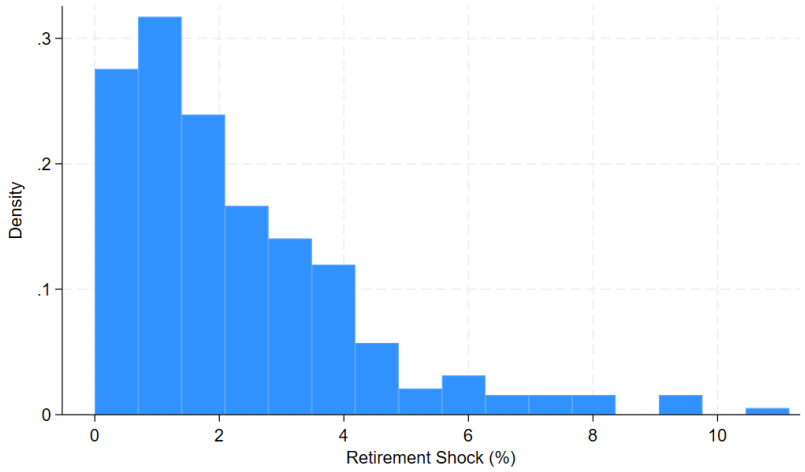
[86] Pension records do not supply the universe of all departures from Caltrans, though. Employees need at least 5 years of service, and must retire no younger than 50.

[87] Employees need to be 50 (and in same cases 52 or 55) to receive their pension.

Covid-19 pandemic on our results. Within each district-year, we calculate statistics for projects *awarded* in district d and year t. The outcomes of interest include project duration, winning bid, and cost overrun, each of which we winsorize at the 2% level. Our final sample has 9,600 projects over 12 districts and 19 years.

We describe our construction of the retirement shock in the main text, but we show the distribution below.

Figure H.4: Distribution of Retirement Shocks



Notes: This figure shows the distribution of retirement shocks in the data. Retirement records from "Transparent California." This figure uses any retirement of any engineer whose final job title was "Transportation Engineer". The denominator for the shock is the number of engineers we estimate in the district in the year 2011 (the total number of engineers in Caltrans in 2011 scaled by the share of projects awarded in that district). We do not have data on employment of engineers by district, or employment of engineers in total before 2011.

Table H.7: Engineer Retirements and Project Mileage

	Mileage		log(Cost per Mile)		Number of
	Mean	Median	Mean	Median	Projects
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	-0.237	-0.105	0.097**	0.039	0.005
	(0.194)	(0.272)	(0.039)	(0.034)	(1.630)
R-squared	0.34	0.31	0.29	0.32	0.81
Observations	228	228	228	228	228
District FE	×	×	×	×	×
Year FE	×	×	×	×	×
Dep. Var. Mean	4.83	9.31	12.61	12.62	48.76

Notes: The table presents the regression of the district-level retirement shock on additional procurement outcomes (project mileage, cost per mile, and number of projects let), as specified in equation 2. The independent variable of interest, $\frac{\text{Retirements}}{\text{Engineers}}$, is measured as a percentage, and uses all engineer retirements. Standard errors are clustered at the district level. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15.

I Survey

The survey, with tabulated responses to each question, is attached following this page. It can also be found at `https://cailinslattery.com/s/Survey-with-Responses.pdf`.