State Capacity and Infrastructure Costs

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Abstract

How much is a good bureaucrat worth? We study this question in the case of U.S. infrastructure construction; a setting where costs are high and rising. We collect new project-level data on infrastructure costs and conduct a survey on how states plan, procure, and deliver these projects. The survey results suggest that low state capacity at the agency delivering the projects is a primary cost driver. We investigate this with administrative data that links individual personnel to infrastructure projects. We find that higher-quality government engineers deliver observationally similar projects at significantly lower cost; going from the 25th to 75th percentile of engineer quality is associated with a 14% reduction in project-level costs, amounting to more than three times the average engineer salary. Further, losing expertise to retirement has substantial consequences: the cost increase arising from engineer departures is six times the size of their wages. Our results highlight the value of experience and human capital in public organizations.

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1 Introduction

To deliver public goods, the government needs enough capacity to operate effectively (Besley and Persson, 2009). The state's capacity includes the bureaucrats who implement policy, enforce regulations, and deliver public goods and services. In the U.S., where public procurement accounts for roughly 25% of all government expenditures, relatively few government employees manage a tremendous amount of money (OECD, 2025). How important is the experience and skill of the bureaucracy for managing government costs?

We study this question in the case of infrastructure provision in the United States. The government does not build infrastructure, it procures it, and government engineers are an input to a complicated public goods provision problem. This is a setting where public concern is growing over both cost and quality: highway construction costs have increased substantially over time (Brooks and Liscow, 2023; Turner et al., 2023) and the cost of urban rail is about three times more expensive in the U.S. than in other rich countries (Goldwyn et al., 2023).[1] Despite the magnitude of spending and the importance of infrastructure as a driver of economic growth, we know little about *why* it costs so much to build and maintain infrastructure in the United States.[2] State capacity—both the practices of the government and the quantity and quality of the personnel—is one piece of this puzzle.

We bring three new pieces of evidence to bear. The first is qualitative: a survey of experts shows that state Departments of Transportation (DOTs) across the country are concerned about a decline in the size and experience of their workforce. We also observe these trends in Census data, and find that states with fewer transportation employees per capita have higher costs. The second is an analysis of the individual engineers who manage projects, wherein we create a measure of engineer quality that captures experience and skill. When a higher quality engineer is assigned to a project, costs are reduced substantially. The third piece of evidence comes from variation in district-level retirements. An increase in retirements is followed by an increase in average project costs, cost overruns, and duration. Retaining high-quality employees and preventing early retirements is therefore one possible policy to manage costs.

We begin by studying highway resurfacing projects, which are the bread and butter of American

[1] Experts have emphasized the poor condition of U.S. transit, roads, and bridges. The fact sheet for the 2021 Infrastructure Investment and Jobs Act stated 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`.

[2] There is a quickly growing literature on infrastructure, and construction more generally, costs in the U.S.—explanations on the high cost of building infrastructure include overregulation and litigation (Klein and Thompson, 2025; Liscow, 2025), citizen opposition (Brooks and Liscow, 2023), competition (Currier, 2025), usage (Turner et al., 2023), overbuilding (Goldwyn et al., 2023), productivity (Goolsbee and Syverson, 2023), and political distortions (Fajgelbaum et al., 2023; Rosenthal, 2017).

infrastructure spending.[3] We start with the basics. How much does it actually cost to resurface a road in the United States? We collect data on *project-level* costs in each state, via public records requests, and then extract details from project plans to calculate the cost per mile of resurfacing: a homogeneous measure that we can compare across projects and space. This dataset is the first of its kind; previous work on infrastructure investment across states relies on aggregate spending data. We document significant variation in costs across states. These cost differences are not explained away by climate, geography, density, or labor costs. Then, we design a survey to document the process by which each state manages procurement and project delivery. We survey the people who plan, manage, and construct these projects—government engineers and private-sector contractors.

Two themes predominate in the survey responses: state capacity and competition.[4] Respondents emphasize that capacity is a constraint; state DOTs are understaffed and retirements are leading to a loss of agency expertise. The states that have "low-capacity" practices—less staffing, reliance on consultants, more frequent contract modifications, and administrative delays—have higher costs per mile. Using Census data, we find that the size of a state's DOT is inversely related to costs—adding one transportation employee per 1,000 residents is correlated with 26% lower costs at the project level. States that engage in practices to increase competition—i.e., bidder outreach—have statistically significant lower resurfacing costs. Practices that have the effect of dampening competition—i.e., subcontracting limits—are correlated with higher costs.[5] Despite low levels of competition throughout the country, the majority of state DOTs do very little outreach to increase the bidder pool. The survey evidence also suggests that competition and capacity are related; higher quality departments (as measured in the survey) are more likely to perform outreach to bidders.

In the second part of the paper, we use administrative data to quantify the role of state capacity in infrastructure delivery; a setting in which a relatively small number of government employees oversee the private contractors who actually build the projects. We expand our analysis beyond resurfacing and study all highway projects in California, a large state with diverse infrastructure delivery needs. This data is unique in including the identity of two government engineers assigned to each project: the "Project Head," who leads for the entire life cycle of the project (the planning, design, and bidding

[3]Total capital transit spending across the U.S. is an order of magnitude less than highway spending (70% of which is rehabilitation and maintenance). In 2022, the Federal Transit Administration reported an expenditure of $27B across all transit authorities, compared to $266B on highways in the same year (Federal Transit Administration, 2022).

[4]Our finding on limited competition driving costs is consistent with a rich literature in industrial organization. See the Hortaçsu and Perrigne (2021) Handbook of Industrial Organization chapter, Section 3, for an overview.

[5]We also collect data on the number of bidders on each project, and find that an additional bidder is associated with 8.3% lower costs per mile. The number of bidders is endogenous to project details that are unobservable to the econometrician. We attempt to control for unobservables by conditioning on the estimated cost predicted by the DOT before bidding begins.

processes), and the "Construction Head," who leads the construction phase under the Project Head.[6]

First, we show that these engineers are important: engineer identity explains about 7% of the variation in costs. Then, we take a parametric approach to directly study the relationship between engineer *quality* and project cost. While engineer assignment to projects is non-random, we show that the most experienced engineers are assigned to the most complicated projects—a bias that works against our finding a negative effect between quality and cost. We use personnel data on compensation to create a quality measure for each engineer. The measure is a residual of employees' compensation which captures their experience, performance, and job-specific training. Moving from the 25th to 75th percentile of Project Head quality is associated with a 14% reduction in costs per mile, amounting to more than three times the average engineer salary. We also find important complementarities between engineers: high-quality Construction Heads only meaningfully reduce total costs when the Project Head is high quality.[7] This provides further insight into the production function of the state.[8]

Next, we explore how high-quality Project Heads are able to reduce costs. Because the Project Head manages the planning, design, and bidding phases of the project, their effort may influence the level of competition for the contract. We study the heterogeneous effects of engineer quality across more or less competitive markets for highway projects. Quality has a larger effect in markets with less competition. In fact, engineer quality leads to the largest cost savings in markets where there are many more potential bidders than actual bidders, i.e., where there are relatively low levels of participation in the competition for the contracts. This finding emphasizes the link between capacity and competition and provides suggestive evidence for a mechanism by which high-quality engineers can reduce costs: increasing bidder participation.

Lastly, we exploit variation in capacity arising from engineer retirements. We estimate the direct effect of retirement shocks on district-level productivity; this combines both a potential workload effect induced by retirements and a decrease in the average experience of employees in the district.[9] We find that increases in engineer retirement levels within a district are associated with increases in total cost, cost overrun, and duration for projects let in the same year. A retirement shock equivalent to one percent of a district's staff engineers coincides with a 4.3% increase in project costs, a 5.6% increase in cost overruns, and a 3.2% increase in project duration, at the mean. The engineers appear to pay for themselves many times over: the cost increases resulting from their departure are six times

[6]The positions are "Project Manager" and "Resident Engineer" officially. We alter the notation for expositional purposes.

[7]We find more evidence of an effect of the Construction Head on cost overruns. This makes sense: the Construction Head leads the construction phase, which is where cost overruns occur.

[8]In short, high-quality engineers may be constrained by earlier decisions and investments in planning and design.

[9]California's DOT is organized into 12 geographic districts, each with its own office and management team.

as large as their wages.

The cost of losing experienced engineers, in terms of how much the government is paying to build and maintain the road network, is much larger than any cost savings from lower wage bills. In fact, our back-of-the-envelope analysis suggests that California's DOT should be willing to increase the compensation of high-quality engineers by more than $300,000 per year to prevent them from leaving for the private sector.[10] For comparison, the maximum annual salary for a senior engineer at the DOT is $168,000 (CalHR, 2025). Wage compression in the public sector may be exacerbating capacity issues within government—experienced engineers can retire with a pension from the public sector at a relatively young age and go on to make more in the private sector, oftentimes consulting for the government. The results suggest that, if the government could retain substantially higher-quality engineers by moving toward the private sector wage, it would reduce total costs.[11]

One reason why experience may be so valuable in this setting is the extent of regulation (Bosio et al., 2022; Klein and Thompson, 2025).[12] The qualitative findings from the survey emphasize that new employees at state DOTs are unfamiliar with the many rules, requirements, and specifications of the agency, which can lead to mistakes and delays. We also find that in states where survey respondents document "burdensome administrative processes" costs are higher. To proxy administrative burden, we collect data on the length of the documents that bidders must complete in each state. A one standard deviation increase in page length is associated with 16% higher costs.

Although our findings are specific to the U.S. infrastructure setting, rising fiscal pressures have limited the ability of governments worldwide to recruit and retain skilled employees.[13] Recent efforts purportedly aimed at increasing government efficiency in the United States have focused on reducing the size of the federal bureaucracy. Within the first few months of the second Trump administration, the Department of Governmental Efficiency reduced the federal workforce by over 150,000 employees (Choi et al., 2025; Sullivan, 2025). The first round of reductions provided incentives to encourage early retirements of career civil servants. These efforts are motivated by cost savings, but the employees targeted are those with the most experience and job-specific human capital. This paper shows that, if government is going to provide public goods, job cuts may increase overall costs instead.

[10] We find that a one standard deviation increase in engineer quality saves the government between $475,000 and $750,000 per year.

[11] In contrast to Lazear (1979), our retirement results suggest that workers (public sector engineers) are paid less than their marginal product when they get older, instead of more.

[12] Consistent with the model and evidence in Bosio et al. (2022), our findings suggest that infrastructure procurement in the United States would benefit from less regulation, not more.

[13] In the wake of the Great Recession, many state governments responded to budget gaps with layoffs and hiring freezes (Gordon, 2012; Sherman and Lane, 2009). Persistent budget challenges have led states to meet their balanced budget requirements by not having as many employees, sometimes not even filling open spots (Phaneuf, 2022).

Related Literature. As a first contribution, we provide new data and evidence on infrastructure costs in the United States. Evidence on the cost of providing infrastructure in the U.S. is sparse. Brooks and Liscow (2023) find suggestive evidence that rising highway construction costs in the late 20th century were driven by increases in citizen voice and the resulting costly demands. Turner et al. (2023) find that input prices are more important for resurfacing, over time. This paper further develops our understanding of infrastructure cost drivers and provides new evidence for the importance of state capacity. We are able to do this by collecting new project-level data. A lack of comprehensive data has been a significant roadblock for researchers—many studies instead take a case study approach and look at a single megaproject (e.g., Fajgelbaum et al., 2023), or use aggregate spending data (e.g., Brooks and Liscow, 2023).[14]

Second, we contribute to an emerging literature on measuring the effectiveness of public managers. A primary difficulty in this literature is linking managers to measurable outcomes, which makes procurement a particularly good setting to study (Bandiera et al., 2021, 2009; Best et al., 2023; Decarolis et al., 2020).[15] This is the first paper to our knowledge to study the role of the individual engineer in infrastructure procurement and delivery.[16] Most of the procurement literature studies the procurement of off-the-shelf goods, where the role of the bureaucrat is constrained to bid letting and bid evaluation. In other words, there is no role for the individual to impact costs outside of the auction. Because the procurement of highway construction is complicated, the individual bureaucrat can affect costs via their effort in planning, bidding, and contract supervision. Another difficulty in this literature is comparing types of procured goods or services. While we take a complicated procurement and delivery setting, we are able to create a like-for-like measure of cost per mile that facilitates comparison across projects, rather than the typically-used measure of cost overruns. Costs are our primary interest; if bids come in high but projects never overrun then the U.S. would still have an infrastructure cost problem. Therefore, we can quantify how important engineer quality can be to deliver infrastructure at a lower cost—an objective of governments across the world.

Third, we provide evidence on *how* agencies and individuals matter for state effectiveness, in the

[14]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 U.S. were more expensive than projects in other G-20 nations (Rosenthal, 2017, 2018). The GAO ended up running into significant difficulties, and was not able to deliver a report on cost drivers, citing data limitations and the complexity of projects as the main impediments.

[15]Muñoz and Otero (2025) and Fenizia (2022) are able to do this outside of the procurement setting: Muñoz and Otero (2025) studies the effect CEOs of public hospitals in Chile on patient outcomes and Fenizia (2022) studies the effect of managers on processing times in social security offices in Italy.

[16]There is also a relevant literature on individual bureaucrat quality and the incentives they face (e.g., Bertrand et al., 2019; Dal Bó et al., 2013; Rasul and Rogger, 2017), and more generally, a literature on management practices and manager quality in the private sector (Bertrand and Schoar, 2003; Bloom and Van Reenen, 2007; Metcalfe et al., 2023).

context of the complicated public goods delivery problem of infrastructure. We study the determinants of bureaucratic competence with both the survey that links realized costs to DOT practices and our analysis of individual engineer quality and retirements in California. Most of the literature on state capacity focuses on developing countries, presumably partly based on the belief that high-income countries have the capacity to efficiently deliver goods and services (Besley and Persson, 2009). Substantial heterogeneity in the cost of public good provision across advanced economies calls this view into question (e.g., Goldwyn et al., 2023, for transit). Our survey, not unlike a survey of management practices across firms (Bloom and Van Reenen, 2007), measures government practices across states. This allows us to examine exactly how differences in agency planning, procurement, and project delivery relate to differences in realized costs.

Our survey is inspired by the World Bank Doing Business Procurement Survey (Bosio et al., 2022), and benefits from a rich empirical auction literature that studies how the design and implementation of procurement practices can have implications for costs.[17] The survey allows us to bridge the industrial organization literature with the literature on organizational and state capacity. While much of the industrial organization literature studies the effect of the auction design on costs, our approach focuses on the *process* of running the auction (not unlike Lacetera et al., 2016, on the performance of auctioneers). We uncover important suggestive evidence that would not have been attainable from studying quasi-experimental variation in particular auction practices.

There is a rich literature on the role of competition in procurement auctions—though the evidence remains mixed, and a lack of competition is a feature of many government contracting settings (Kang and Miller, 2022). The theory implies that an additional bidder should decrease costs (Milgrom and Weber, 1982), assuming entrants draw from the same cost distribution. Interventions which encourage additional bidders have been shown to both increase and decrease costs, depending on the setting (Carril et al., 2022; Coviello and Mariniello, 2014). Our survey findings suggest that supply-side factors are an important determinant of costs in U.S. infrastructure delivery (consistent with Allende et al., 2024, for pharmaceuticals).[18,19] We also show that limited competition can interact with engineer quality. This is an additional channel through which experience and effort can reduce costs—the cost-saving benefits of competition may partly be generated from the efforts of state personnel.

[17] We provide a review of the literature, and how it links to specific hypotheses about costs, in Appendix A.

[18] Allende et al. (2024) study public procurement costs in the pharmaceutical market in Chile. They find an additional seller reduces prices by 11.7%, while we find an additional bidder is associated with a 8.3% decrease in final costs.

[19] This also relates to a burgeoning literature on productivity and market power in the U.S. construction industry (D'Amico et al., 2024; Goolsbee and Syverson, 2023; Kroft et al., 2022).

2 Data and Context

We have collected data from many different sources, which we describe in this section and, in more detail, in the appendix. To give an overview, there are three main groups of data: (1) cross-state data on project-level infrastructure costs, (2) cross-state survey data on infrastructure procurement and project delivery processes, and (3) project-level cost and personnel data from the state of California. We will use the cross-state project cost data and survey data to produce descriptives, and then we will use the data from California to analyze the effect of engineer quality and engineer retirements.

2.1 Project-Level Costs

The first step to understanding infrastructure cost drivers is to accurately measure costs. Unfortunately, no comprehensive dataset exists; the federal government does not require states to report project-level costs on federally funded projects.[20,21] We collect project-level cost data by requesting administrative data from each state DOT, via 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.[22] We will use "cost" to refer to the amount paid to the contractor; our data on costs does not include expenses internal to the DOT, which are not available disaggregated to the project level. We also collect data on the scope of each project, allowing us to calculate the cost per mile.[23]

To facilitate cost comparisons across projects and states, we construct a subsample of projects that meet predetermined criteria.[24] 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). Along with facilitating

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

[21] Therefore, most research on the topic uses aggregate (state-level) spending, or detailed bid data from one state. The Federal Highway Administration 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. We need detailed project-level data in order to facilitate a comparison of similar projects across states. See Brooks (2025) for more on difficulties in measuring costs.

[22] 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.4 and D.5 show that there is a tight relationship between bids and realized costs for these type of projects.

[23] 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.

[24] Our goal is to create a sample of projects that are similar to the case study project described in the survey.

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 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 that project, to give the reader some additional context.

Cost per mile is our primary outcome of interest.[25] This is a departure from much of the literature and policy discussion, which uses cost overrun as the measure of project success or costs. However, cost 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.

The majority of projects in the subsample (95%) cost under $1 million per mile; average cost is about $368,000 per mile, and the median is $226,000 per mile. The 25th percentile is $131,000 per mile, and the 75th percentile is $417,000 (Appendix Figure D.2). Appendix Figure D.1 shows substantial variation in average costs across states, and the coefficient of variation is twice as high for the full sample as it is within state.[26] For example, mean cost per mile is twice as expensive in South Carolina as in the neighboring states of Georgia and North Carolina.[27,28,29] Large variation in costs across states persists even after controlling for observables like weather and labor costs (Appendix Figure D.1). We want to understand what drives these differences.

2.1.1 Observables and Costs

Table 1 shows the relationship between project-level resurfacing costs (log cost per mile) and previously established cost drivers, which include project-level details, local characteristics, and weather.[30,31] The standard errors are clustered at the state level, and the main analysis considers 5 projects per

[25] Specifically, we study cost per lane-mile, such that the mileage captures both the length and the width of the project.

[26] For the full sample the coefficient of variation is 1.38. The average coefficient of variation within state is 0.61. When we use more than 5 projects per state, the coefficient of variation across all projects is 2.68, while the average within state CV is 1.01 (and 0.60 at the median).

[27] Appendix Figure D.2 shows that the majority of the subsample contracts have a contract size of under $5 million, as was specified in the case study.

[28] The average standard deviation of cost per mile of projects within states is $260,000, while the median is $149,000. The standard deviation of cost per mile of projects across all states is $506,000.

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

[30] Descriptive statistics for all of the variables are displayed in Appendix Table E.1. External data sources are described in Appendix F.

[31] We talked on background to many helpful DOT engineers to verify these established cost drivers.

Table 1: Project Costs and Observable Cost Drivers

	Project-Level log(Cost per 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 are weighted so each state is equally represented. We do not have all the project and local characteristics for the larger sample, we use state averages and miles instead of lane-miles. Column (5) aggregates our data to the state level, and Column (6) uses the FHWA spending on resurfacing and maintenance per vehicle mile as the outcome. 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 E.1. Standard errors are clustered at the state level. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15.

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 in lane-miles ("Mileage"), and a dummy for whether the project is on a state highway, as opposed to a U.S. highway ("State-Highway").[32] Column (1) shows that complex projects are more expensive and there are fixed costs of resurfacing—cost per mile is decreasing in total mileage—which is consistent with discussions we have had with highway engineers.

In Column (2) we add state and local characteristics that can affect resurfacing costs. This

[32]For example, a "complex" project could include roadway reconfiguration or utility work along with the resurfacing. This affects only 15 (6%) projects. Column (1) shows that as expected, the complex projects are more expensive.

includes labor inputs, as measured by local wages in the "Highway, Bridge, and Street Construction" industry.[33] We find that wages are positively correlated with costs, as expected. Population density in the county of the project is also positively correlated with costs. This could be due to 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 construction. The next set of variables capture the climate of the state. States with more snow and longer winters should 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. We find that costs are higher in states with more snow and lower in warmer states.[34]

In Column (3), we add state-level measurements of road roughness, where a higher value represents more roughness. FHWA mandates that states collect these data annually.[35] 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.[36] 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.[37] 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.1).

Finally, we compare our cost data with the Federal Highway Authority (FHWA) Highway Statistics

[33]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).

[34]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.

[35]This is the International Roughness Index, and we use the average of the roughness measure from 2014, 2018, and 2019. It measures the total amount of vertical motion, in either direction, that a vehicle's suspension experiences in a kilometer of travel on a given road. 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.

[36]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.

[37]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.

data. For this analysis, we average our data at the state level because the FHWA data are only available as a state-level aggregate.[38,39,40] Columns (5) and (6) of Table 1 show the results. Our data, when aggregated, is highly correlated with state-level weather and road roughness. There is no such relationship between these variables and the FHWA data.[41]

2.2 Planning, Procurement, and Project Delivery

Given project-level cost data, we proceed to collect data on how these projects are planned, procured, and delivered. We develop a survey with two aims: (1) to document what stakeholders say drive costs, and (2) to explore how variation in costs correlates with variation in DOT processes. As background, we provide a brief overview and timeline on the state DOT process for completing a standard resurfacing project. Then, we proceed with details on the survey design and distribution.

2.2.1 A Brief Primer

Planning 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 planning 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 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 their bid to the DOT. All contracts for federally funded resurfacing projects are awarded via a unit bidding process, where a contractor's total bid is the aggregation of their bid on each component of the project

[38] For closeness of comparison, we take resurfacing and maintenance cost series from FHWA, from 2014, 2018, and 2019. This data is not available for 2015-2017. See Appendix D.2 for more details for the construction of the series.

[39] A primary challenge in using the FHWA 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. 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.

[40] The correlation between the two series (our data and the FHWA) is 0.03.

[41] This could also be due to widely varying reporting standards across the country (Liscow, 2024). See Appendix D.2 for further comparison between the FHWA series and our data.

(Appendix Figure A.1). The lowest bid wins, unless the DOT determines there is a reason to exclude a bidder (due to their 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.[42] The DOT inspects the contractor's work, coordinates traffic rerouting and road closure, and negotiates changes to the contract through a process known as "change orders." A change to the quantity of an input used, the contracted price of input, additional work, or additional time can necessitate a change order.[43]

2.2.2 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). As 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 and delivery process of the project.

Our 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 not an Interstate). The road would extend from the outskirts of a mid-sized city into the surrounding rural area, with an asphalt overlay of 1 inch. The estimated value of the contract is less than $5 million.[44]

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 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.[45]

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 planning, procurement,

[42] The prime contractor may subcontract parts of the project to other private firms (see Appendix J for more details).
[43] See Appendix C for examples of standard change orders in this setting.
[44] See, as an example, the project from our data that we discuss in Appendix B.
[45] Road expansion and new construction fell from 53% to 28% of outlays.

and delivery is for resurfacing, it is likely even more challenging for more complicated projects.[46,47]

The survey questions are organized roughly chronologically over the course of a typical project. We ask about a variety of features of the planning, procurement and construction processes, all which have the potential to affect costs. The survey is distributed directly to DOT employees and to private-sector road builders (contractors) via email. The aim was to collect at least one response from each state DOT. We have 123 responses from DOT officials in 50 states, and 211 survey responses from contractors in 47 states. More details on the survey and distribution are available in Appendix G. The full survey is available in Appendix O.

2.3 Government Engineers

The final set of data concerns the engineers that design and deliver highway construction projects, 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.

Project-Level Details and Personnel We link two administrative datasets from Caltrans in order to create a dataset of project details and the associated personnel.[48] This final dataset includes project characteristics (district, location, route, description, length), outcome variables (winning bid, project duration, and final cost), and the identity of two engineers assigned to each project (Project Head and Construction Head). The head project engineer ("Project Head") oversees the entire life cycle of the project, from planning to construction. The head construction engineer ("Construction Head") is the lead employee on the ground who communicates with the contractor throughout the construction phase.

The project-level data from Caltrans includes all types of highway infrastructure projects; we do not subset to only resurfacing projects. We use this data for an analysis of individual engineer quality

[46] 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 O), 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.

[47] 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" (Rosenthal, 2018).

[48] The two datasets are a "construction" dataset and a "project delivery" dataset. The construction dataset includes projects that were awarded between 2000 and 2023. A subset of the construction data spans 1970-2023, but this file only includes project descriptions and the identity of Construction Heads, not final costs. The second Caltrans dataset spans 2011-2023 and includes information on budget and spending for other phases of the project (not only the construction phase).

on project costs (Section 4) and an analysis of retirements on district-level costs (Section 5).

Salary, Benefits, and Retirements We collect data on the salary and benefits of all Caltrans engineers in our project-level data from the nonprofit Transparent California. Transparent California assembles data on California state employees through public records requests, and then publishes this data in a searchable website. We match Caltrans engineer by name, agency, and year, therefore we have the compensation for each engineer in each year we observe them in the project-level data. We have a dataset with the retirement year, name, job title, district, and pension for each retired Caltrans engineer (not only the engineers we observe in our project-level data), from the same source.[49] We aggregate the number of retirements, by job title, to create our district-level retirement shock.

Firms and Bidders Lastly, we have administrative data on bidders for a subset of the Caltrans projects in our sample. This covers 2018-2023, and includes the name of each individual bidder and their bid, for each project. We use this to create a set of potential bidders by project type and district.[50] We use this potential bidder data to explore heterogeneity in the engineer quality effect.

3 Cross-State Evidence on Infrastructure Cost Drivers

Our survey allows us to document the process by which state DOTs plan, procure, and deliver infrastructure projects. We also detail the issues and practices that the stakeholders—DOT engineers and private sector contractors—think drive costs. Then, we correlate the survey responses with the cost data.

3.1 Variation in Practices

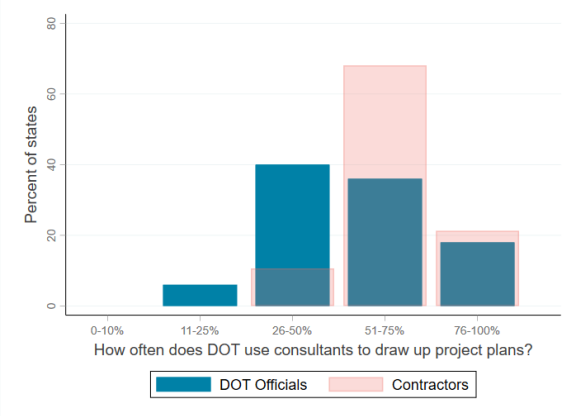
We begin by highlighting the variation in practices across states. There are many questions in the survey, and therefore this section only serves as a brief overview.[51] First, Figure 1(a) shows how often a DOT relies on consultants to draw up project plans. Reliance on consultants can be a symptom of reduced capacity and can lead to increased costs (Levin and Tadelis, 2010; TxDOT, 2010). After developing project plans and cost estimates, there is variation in how much information is shared with bidders (Panel (b)). While providing more information on project plans and estimated cost can reduce costs by decreasing uncertainty to bidders and allowing them to make more accurate bids

[49] Transparent California requests this data from CalPERS, the California Public Employee Retirement System.

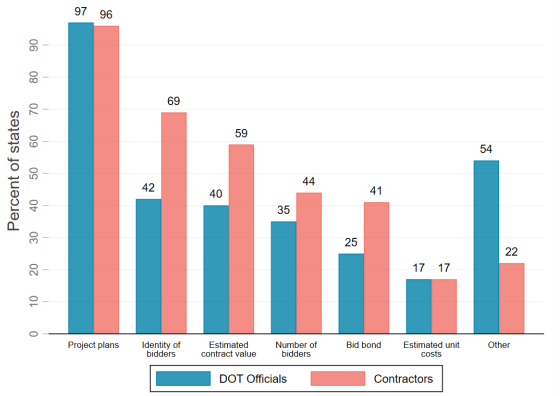
[50] We describe the construction of this variable in Section 4.

[51] Appendix O reports the distribution of responses for each survey question, while Appendix H presents further descriptives.

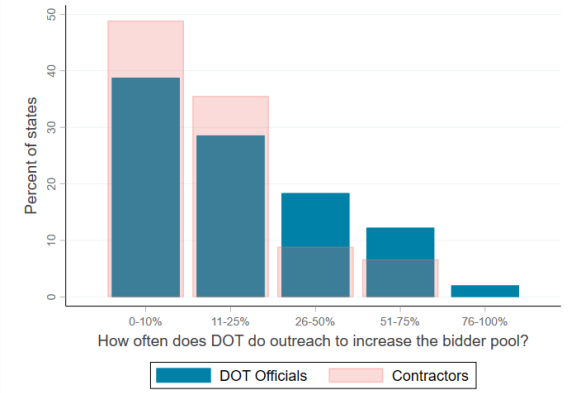
Figure 1: How State DOTs Plan, Procure, and Manage Projects



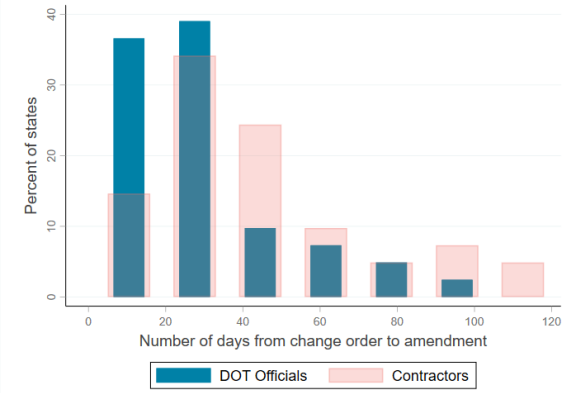
(a) Consultant Usage



(b) Information Published to Bidders

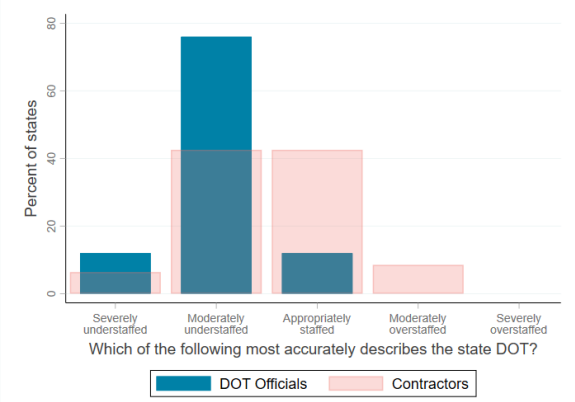


(c) Bidder Outreach

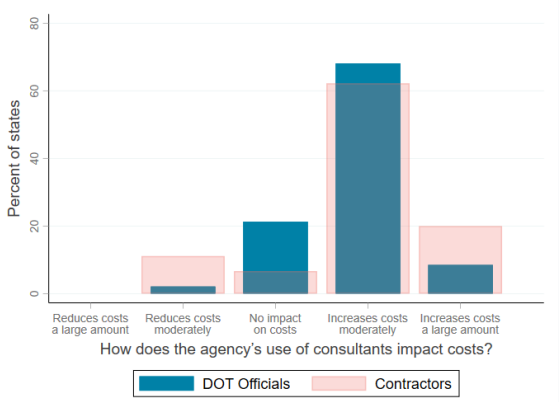


(d) Timing of Change Orders

I. Variation in Processes



(e) Staffing Levels



(f) Consultant Cost

II. Consensus in Concerns

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 O. Figure (b) displays the responses to the following question: "*What information does the agency publish before bids are due? Select all that apply.*"

(De Silva et al., 2008), providing information on bidders' competitors can increase costs (Barrus and Scott, 2020).

Panel (c) shows the variation in how often states do outreach in order to increase the pool of bidders. The evidence on increased publicity on realized costs is mixed; generally the effects of additional entry depend on the quality of the new entrants (Carril et al., 2022; Coviello and Mariniello, 2014). Finally, Panel (d) shows variation in timing in the construction phase. Here, we ask how many days pass between the request for a change order and the signing of the contract amendment. The median number of days reported is 30, for both DOT officials and contractors, and the standard deviation is 25 days. Construction delays are positively correlated with project costs (Appendix Figure D.6).

3.2 Reported Cost Drivers

We begin our exploration of cost drivers with a textual analysis of responses to the free response survey 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 DOT officials and contractors before they are primed by the specific questions we ask.

Competition is a frequently cited cost driver.[52] DOT officials mention competition explicitly when asked to describe cost drivers in their states.[53] In fact, in a subset of the data where we can reasonably control for project unobservables, we find that one additional bidder reduces project cost per mile by about 8.3% (Table 2, Column (3)). Despite the focus on competition in the free response, Figure 1(c) shows that 70% of states *rarely* do bidder outreach. This could be because the DOT has low capacity or willingness to do outreach, or because they know the market well and no other capable firms exist in the area.[54,55] In the Census data, we find that a majority of states experienced a decrease in

[52]Appendix Figure H.10 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 (Appendix Table H.2).

[53]Consider these three quotes from the free response: (1) *"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."* (2) *"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."* (3) *"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."*

[54]We note that contractors also mention competition as a cost driver, but they focus on competition in the downstream market for subcontractors (and policies that they view as restricting subcontracting relationships, such as the Disadvantaged Business Enterprise (DBE) program). We discuss this further in Appendix J.

[55]The survey responses of the contractors also demonstrate how a lack of competition can have immediate implications for costs. In states where competition is mentioned as a concern, contractors report expecting to face fewer competitors (Appendix Figure H.7). The fewer competitors a contractor expects to face, the higher the probability they know all

Table 2: Project Costs and Hypothesized Cost Drivers

	Log(Cost per Mile)		
	(1)	(2)	(3)
Highway Employment per Capita (1,000)	-0.263+	-0.245	0.022
	(0.164)	(0.229)	(0.113)
Bid Document Page Length (per 10 pages)		0.025*	
		(0.013)	
Number of Bidders			-0.083**
			(0.035)
Engineer's Estimate (log(Cost per Mile))			0.838***
			(0.158)
Observations	250	125	94
R-squared	0.37	0.50	0.68

Notes: All columns use the regression specification from Column (2) of Table 1 (project details, local characteristics, state weather). 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. Standard errors are clustered at the state level. In Columns (2) and (3) we have relatively few clusters; results are robust to using wild cluster bootstrap methods to cluster at the state level. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15

establishments in the Highway Construction industry over the period of 2007-2017 (Appendix Figure F.1), with the median state experiencing a 13% decrease.[56]

The capacity of the agency was the other most commonly mentioned issue in the free response. Phrases such as "poor plan," "change order," and "plan error" suggest inadequate bidding plans, one common 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.*" Further, phrases such as "certify payroll," "paperwork require," and "red tape" were common, relating to capacity issues stemming from administrative burden.[57]

In fact, there is remarkable agreement among state DOT employees on capacity, or, more accurately, a lack thereof. Figure 1(e) shows that almost 90% of respondents report that their state DOT is severely or moderately understaffed.[58] We allowed respondents to elaborate on their experiences with DOT employees in a free response. Here, both contractors and DOT officials emphasize issues with staffing and experience. To give a few examples, contractors write:

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 H.1).

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

[57] The responses about administrative burden also relate to the role of overregulation in this setting (Klein and Thompson, 2025). We posit this is one reason why state capacity is so important in this setting—the state needs sufficient capacity to comply with the regulations.

[58] Respondents also report that employee quality is relatively high; 90% of the respondents rated the quality of the employees at the DOT as "very high" or "moderately high" (Appendix Figure H.4). Contractors are considerably more likely to think that state DOTs are understaffed than overstaffed—though, on average, they do not feel as strongly as the DOT officials. They also feel less positive about employee quality—most think that employees are of neither high nor low quality.

- "*All of the individuals that I have worked with and were exceptionally talented have left due to lack of leadership at the top and we are left to deal with individuals that have limited experience and knowledge base. This has driven cost of construction significantly.*"
- "*As in all market sectors, the DOT workforce is getting younger and less experienced all of the time. This impacts work through delay in decision making and poor decision making.*"
- "*10-30 years ago the DOT had very well trained and knowledgeable employees, who understood construction and could make quick decisions in the field. Today, most of the DOT employees are lacking experience, hesitant to make simple decisions, and rely too much on consultants, who in many cases are not much better.*"
- "*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 DOT officials agree with the sentiment, though they are generally more positive about quality:

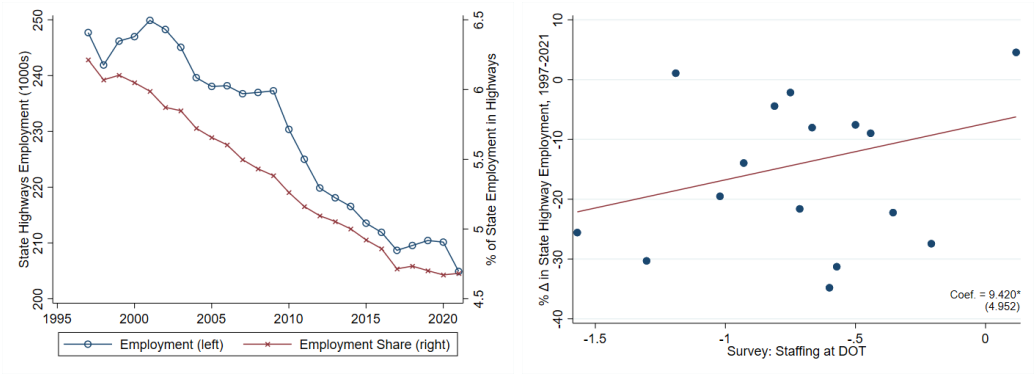
- "*Competent but increasingly short staffed and less experienced employees with a high turnover*"
- "*Dedicated great workers just becoming harder to attract and retain staff*"
- "*We have a lot of talented individuals who are in the later stages of their career. Our issue in [state] is attracting new talent, the current candidate pool is very weak.*"
- "*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.*"

A common way to deal with understaffing is to hire consultants that can do the work of the DOT engineer. Figure 1(f) shows that contractors and DOT officials are aligned on their view of consultants—80% of respondents report that using consultants increases costs at least moderately. 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.[59]

We use administrative data on public sector employment to further 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 Annual Survey of Public Sector Employment and Payroll) declined 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 2(a)). The Census data is consistent with the survey evidence: states that experienced the largest losses in employment are

[59] 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.*"

Figure 2: 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 (U.S. 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 staffing survey variable is coded with a 0 if the respondent chose "Appropriately staffed", -2 if they chose "Severely understaffed,"and +2 if they chose "Severely overstaffed".

more likely to report being understaffed.[60] This also is correlated with realized costs: an increase of one DOT employee per thousand people is associated with a 26% decrease in project costs (Table 2).

Finally, we ask what DOT officials and contractors think drives cost *overruns* (Appendix Figure H.5).[61,62] Consistent with the findings from the free response, the most common cause of cost overruns cited by both DOT 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 can be as simple as an increase in quantity or a change in material, and are directly downstream of poor planning (see Appendix C for a few illustrative examples).

A narrative emerges from these descriptives: states with fewer or less experienced employees outsource work to consultants and do not invest in high-quality project plans. A lack of specificity in project plans increases uncertainty for contractors, which will be priced into their bids, directly leading to higher costs.[63] This also necessitates ex-post changes to the materials and work needed to complete the project (change orders), which lead to higher costs through delays and costly renegotiation.

[60]Employment in highways includes the DOT engineers, which is the main personnel of interest for the delivery of highway resurfacing projects. However, this series includes all employment in the umbrella of "highways". The Census definition follows: "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."

[61]We also ask respondents whether there are labor or subcontracting requirements that increase costs. The responses are tabulated in Appendix Figure H.6.

[62]The question is a bit more specific than the free response question on cost drivers, because of the focus on overrun (i.e., ex 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.

[63]Bolotnyy and Vasserman (2023) show the importance of risk on firms' bidding strategies for bridge maintenance projects in Massachusetts.

3.3 Survey Correlates

We take the survey responses to the cost data to examine how much of the variation in costs is explained by differences in DOT processes across states.[64] 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 DOT 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.

We find that most state-level practices do not correlate with realized costs: only 7 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).[65] The correlations that do emerge are consistent with the two themes that predominated the descriptive statistics: 1) limited state DOT capacity and 2) limited competition.

Figure 3 presents the significant correlations. Results for all of the survey responses can be found in Appendix I, including the unadjusted p-values, which are often much smaller.[66] We note that the survey responses have explanatory power. When we use only the observable cost drivers (Table 1), we can explain about 35% of the variation in costs between states and projects. When we add all of the survey variables, this increases to 60% (Appendix Table I.5).

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.[67] In fact, we find that states where respondents cite consultant use as a cost driver do have

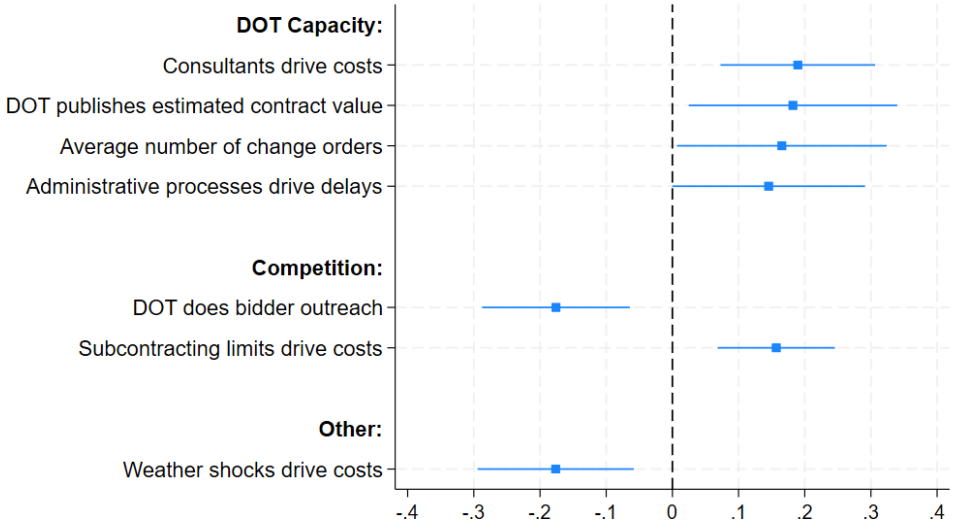
[64] Appendix H provides further descriptives from the survey, with an emphasis on variation in practices across states. Appendix O reports the distribution of responses for each survey question.

[65] 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 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; Romano and Wolf, 2005a,b). We consider all of our survey results listed in Appendix I to be in the same "family of hypotheses."

[66] When we consider the unadjusted p-values we find that 12 of the survey responses are significant at the 10% level, instead of 7. Most are closely related to the variables we discuss in this section (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).

[67] 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 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. The report writes: "*Erosion of state DOTs' in-house expertise as a result of staff cuts and*

Figure 3: 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 after adjusting for multiple hypothesis testing using the Romano-Wolf multiple hypothesis correction (Romano and Wolf, 2016). The dependent variable is log cost per 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 with mean zero and unit variance.

significantly higher costs.[68] 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. We find that a one standard deviation increase in reported consultant costs is associated with a 19% increase in cost per mile, or a $70,000 increase per mile at the mean.[69]

The next correlation concerns the information that the DOT provides to bidders. We find that publishing the total estimated cost of the project is positively correlated with costs. At first blush, this may seem surprising, as this is information that could be valuable to the bidder in developing their own cost estimates. However, it is not as informative as providing estimates at the unit (item) level, which some states do. Alternatively, it is possible that the state systematically overestimates costs and anchors bidders to an inflated price. To probe this further, we include all of the potential pieces of information that the DOT can share with bidders in one regression (Appendix Table I.6).

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). See Appendix N for more.

[68] 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 is not because the consultants bill at a high hourly rate (which can also be true).

[69] 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." This correlation displays the largest magnitude of our statistically significant results, indicating that consultants could be one of the key mechanisms through which weak state DOT capacity could increase costs.

Here, we find that, as we hypothesize, providing project plans and unit cost estimates is negatively correlated with costs, and providing information about the level of competition is positively correlated with costs, but these correlations are not statistically significant.

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. While change orders are expected with more complex projects, the project we describe in the survey case study is for fairly straightforward resurfacing work. Therefore, we interpret change orders as a downstream symptom of poor administrative capacity at a state DOT. This is consistent with institutional details—change orders arise when there is additional work that was not specified in the plans, work that needs to be redone because of changes in plans, or simple changes in the quantity of inputs because of mistakes in the plans (see Appendix C for examples). The correlation suggests that one additional change order is associated with a $25,000 increase in cost per 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. Administrative delays are a likely 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 respondents that cite administrative processes as a source of delays is associated with a 14% increase in cost per mile.[70]

As an external measure of burdensome administrative processes, we collect data on the length of the documents that bidders need to submit to compete for the project. These bid documents, or "packets," are required for a bid proposal and are published as templates for contractors to fill out.[71] 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 these documents in our sample is 164 pages, with a standard deviation of 80 pages. We find that one standard deviation increase in page length is correlated with 16% higher costs per mile (Table 2)—another piece of suggestive evidence that administrative burden can drive costs. This may operate through delays and time cost to the DOT employees preparing and reviewing compliance documents, or it may operate through competition, deterring potential bidders

[70]This survey response explicitly links burdensome administrative processes with delays. This also relates to the theory of overregulation (Bosio et al., 2022; Klein and Thompson, 2025), which we discuss in the introduction and conclusion. We note that burdensome administrative processes can also increase costs by discouraging entry (Hjort et al., 2020).

[71]We collect data on "bid packets" from various state DOT agencies, specifically related to state highway resurfacing projects, and measure the page length of the PDFs. We manually search online for publicly available templates and are able to successfully find PDFs for 25 states. See Appendix F.4 for more details.

who do not have the experience necessary to properly complete the packet.[72]

Competition The next two statistically significant correlations concern competition. 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.[73] 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 mile, or $1 million at the project level. This is striking, given the relatively low levels of bidder outreach we see across states (Figure 1(c)).

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.[74] State governments can restrict the share of a contract's dollar value that bidders are allowed to subcontract or restrict the set of eligible subcontracting firms.[75,76] States also vary in how simple it is to add subcontractors to a project. We find that a one standard deviation increase in citing issues with subcontracting limits is associated with a 15.7% increase in costs.

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?*" One interpretation of this correlation is that in states where the main reason for cost overrun is weather, things are operating smoothly and costs are relatively low. Appendix Tables I.1-I.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.[77]

[72] Hjort et al. (2020) conduct an information experiment in Liberia, where they teach firms how to navigate the formal procurement process. Treated firms win three times as many contracts a year after the experiment.

[73] 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).

[74] 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.

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

[76] Generally, subcontracting limits may be either lower or upper bounds—in the case of Disadvantaged Business Enterprise (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. We further explore the relationship between the DBE program and costs in Appendix J.

[77] 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 Appendix G we introduced five broad hypotheses related to costs: transparency, competition, quality, capacity, and corruption. We discuss the types of questions that relate to each hypothesis with the full results in Appendix I.

4 The Role of the Government Engineer

The narrative from the survey suggests that government capacity and costs are closely related. A lack of capacity at the state DOT has the potential to lower the quality of project plans, either because of under-staffing in-house or outsourcing to consultants with limited institutional knowledge and misaligned incentives (GAO, 2008). A lack of specificity in plans introduces risk to the contractor, which can both increase contractor bids and open up the government to a costly and time-consuming renegotiation process when the scope of project changes. A lack of capacity can also mean less time or effort on bidder outreach, resulting in less competition for the project, the other primary cost driver we find in the survey.[78] We investigate the role of capacity as a cost driver with detailed administrative data from Caltrans, the state of California's DOT. We start by quantifying the relationship between individual engineer *quality*, broadly defined, and the realized costs of standard highway infrastructure projects. Before we discuss our approach in detail we provide some context on the engineer position at Caltrans.

4.1 What Do Caltrans Engineers Do?

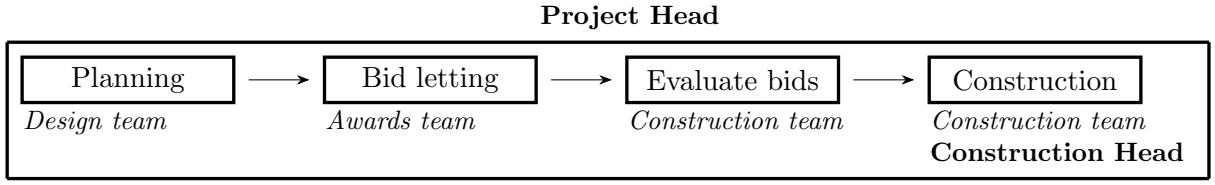
Job Description The majority of engineers at Caltrans—and, therefore, in our data—have the title "Transportation Engineer (Civil)." In our sample, 83% of Construction Heads and 23% of Project Heads have this title, which encompasses many potential tasks (described in Appendix K.1). Engineers can hold this job title throughout their careers. Entry-level transportation engineers begin assisting with plans, environmental reports, and construction team work. As they gain experience and qualifications, they 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. Figure 4 shows each phase of the project, the office or team that is associated with the phase, and the types of engineers involved.[79] In bold, we highlight the engineers that we observe linked to the

[78] Most of the results in Figure 3 related to capacity speak to potential symptoms. It is worth noting that we have suggestive evidence of a more direct—though subjective—measure of capacity: quality of DOT employees. In the survey, we ask, "*How would you rate the quality of the employees 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 (The unadjusted p-value on the employee quality rating is 0.09, the Romano-Wolf p-value is 0.21 , see Appendix I).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 mile.

[79] There is also a pre-planning and approval phase to project delivery which is not pictured in Figure 4. 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. For the senior engineers, communication with the public and developing reports can be an even larger part of the job. Typical tasks for the senior engineers include "supervises the preparation of transportation

Figure 4: Engineers in Project Delivery at Caltrans



project data: the Project Head (at the top) and the Construction Head (in the construction phase). The Project Head is an experienced engineer who is responsible for overseeing the life cycle of the project, from planning to completion.[80] This includes the planning, bid letting, bid evaluation and award, and construction phases of the projects. On the construction team, entry-level transportation engineers start as inspector-engineers. Then, after years of experience and training they are able to be promoted to Construction Head, who is responsible for the contract administration and construction of the project under the leadership of the Project Head.

Engineers and Costs We start by quantifying the role of individual engineers on project-level outcomes. DOT engineers can impact costs with their efforts throughout the planning, bidding and the post-auction (construction) phases. At the planning stage, head project engineers (Project Heads) 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 Project Head and 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 supervisor and Project Head evaluate bids, and can reduce costs by identifying inexperienced contractors or manipulated bids.[81] Lastly, in the construction phase, the Construction Head can work to control cost overruns and delays to ensure projects are 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 Head), and the engineer that manages the construction phase (the Construction Head).[82] We will be able to separately identify the role of engineer quality at these two

and encroachment permits; presents information to the public on transportation engineering matters; represents the Department of Transportation at meetings; prepares correspondence and reports."

[80] In our data, about 70% of Project Heads are at a senior engineer position (Appendix Table L.1).

[81] The construction supervisor is primarily involved in the bid evaluation, and then provides counsel for Construction Heads across many projects.

[82] At Caltrans, these positions are called "Project Manager" and "Resident Engineer," respectively. We change the names for clarity.

levels.

Before we turn to measuring engineer quality, we assess how much of the variation in costs is explained by the individual Project and Construction Head engineers. We do this with a simple regression of project-level log cost per mile on a set of fixed effects: project type, Caltrans district, year, county, route, and finally, engineer. Appendix Table K.1 reports the adjusted R-squared after adding each additional set of fixed effects. The DOT engineers assigned to the project explain an additional 7% of the variation in costs, contributing 15% of the total explanatory power. The majority of engineers in our sample period are only observed as a Project or Construction Head for 1 to 3 projects. Therefore, we take a parametric approach and study the direct relationship between engineer's *quality* and project costs.

4.2 Measuring Engineer Quality

To study the effect of engineer quality on project-level outcomes we take all projects starting between 2011-2018 where we observe both the Construction Heads and Project Heads. This is a sample of approximately 2,400 projects, completed by 300 Project Heads and 500 Construction Heads.

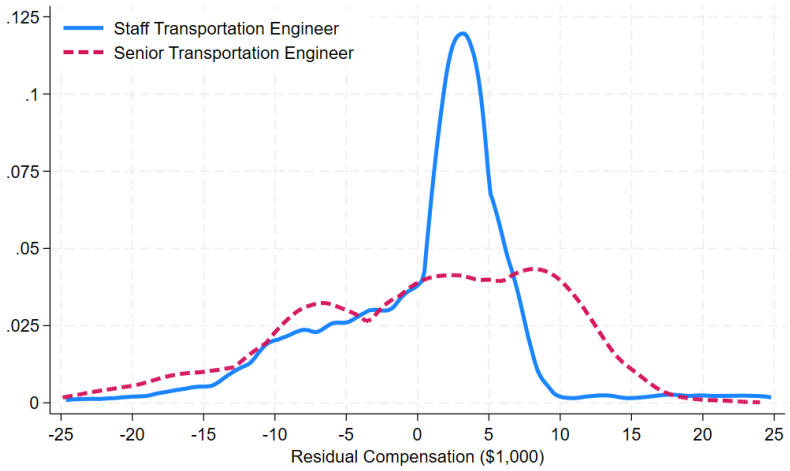
We use our personnel data on engineer compensation in order to create an engineer "quality" measure. We define compensation as the sum of salary and benefits observed for each engineer-year pair in the salary data. A simple regression of job title and year dummies on compensation explains over 80% of the variation in the data (Appendix L.2). Figure 5 shows the distribution of the residualized compensation that results from this regression. This residual is what we will attribute to "quality."[83]

Our quality measure captures higher compensation due to both experience and skill. 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.[84] As an example, the most common position in our data, "Transportation Engineer (Civil)," has a pay schedule with 4 ranks: A-D. Each rank has a pay range. Employees can only progress through the schedule with experience and additional certifications. For example, an employee cannot reach rank D without becoming licensed as a Professional Engineer in the state of California, which

[83] Our approach differs somewhat from those used to measure the impact of another group of public sector professionals, teachers. We seek to explain variation in engineers' productivity with proxies for quality; this is the logical reverse of teacher value-add, which seeks to use differences in output to measure quality (Chetty et al., 2014; Kane and Staiger, 2008). Thematically, our work is closer to Chetty et al. (2011), in which observed teacher experience leads to long-run student gains.

[84] See Appendix L for a further discussion of the data, institutional details, and pay scale for Caltrans engineer.

Figure 5: Residual Compensation of Caltrans Engineers



Notes: This figure shows the distribution of residual compensation, which we will use as our quality measure. We regress compensation on job title and a set of year dummies, and then use the estimates to calculate predicted compensation for each Caltrans employee (see the results in Column (4) of Appendix Table L.2). This figure shows the distribution of the residual. We show the distribution separately for two positions that make up the majority of the sample: Staff Transportation Engineers and Senior Transportation Engineers. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15

Table 3: Engineer Quality versus Years of Experience

	Years of Experience				
	(1)	(2)	(3)	(4)	(5)
Construction Head Quality	0.543***	0.584***	0.609***	0.442**	0.462**
	(0.153)	(0.154)	(0.154)	(0.174)	(0.194)
Adj. R-squared	0.04	0.06	0.08	0.12	0.15
	Number of Projects				
	(1)	(2)	(3)	(4)	(5)
Construction Head Quality	0.861***	0.893***	0.935***	0.901**	1.134***
	(0.310)	(0.314)	(0.314)	(0.371)	(0.424)
Adj. R-squared	0.01	0.07	0.08	0.11	0.15
Job Title FE	×	×	×	×	×
District FE		×	×	×	×
Year FE			×	×	×
Project Cut-off				5	10
Observations	2,106	2,106	2,106	1,690	1,311

Notes: We use the residual from Column (4) in Table L.2 to predict the number of years of experience. Here, we take engineer years on the job from the construction data, where we see Construction Head assignment from 1970-2023. We use the first year we see an employee as a Construction Head 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 (3) - (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.

involves multiple exams as well as schooling and work experience. In short, three reasons for higher pay can enter the residual: experience, professional licensing, and job performance.[85]

Table 3 shows that our quality measure is strongly positively correlated with alternate measures of experience (years of experience and number of projects), which we only have for the Construction Heads.[86,87] We calculate years of experience as the number of years since we first observe the engineer in a historical dataset. This is a noisy proxy—the engineer can work for many years at Caltrans before being assigned as a Construction Head (and therefore, have accumulated significant experience before they are observed in the data). Many engineers are only observed a few times. In Columns (4) and (5) we restrict the sample to engineers that we observe on at least 5, or at least 10, projects over the entire 1970-2023 sample. This increases the explanatory power of our quality measure.

4.3 Empirical Approach

To analyze the impact of engineer quality, 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: mileage, project type p, county c, highway route r, district d, and year t.[88] Subscript j indexes the job title of the Construction Head assigned to the project. We main outcome, y, is log cost per mile.[89] The full specification is as follows:

$$\begin{aligned} Y_{ijprcdt} =& \beta_1 \text{ Quality CH}_{ijdt} + \beta_2 \text{ Quality PH}_{ijdt} + \beta_3 \text{ Quality CH}_{ijdt} \times \text{Quality PH}_{ijdt} \\ &+ \alpha \text{ mileage}_i + \psi_p + \alpha_p \text{ mileage}_i \times \psi_p + \nu_r + \phi_c + \gamma_d + \phi_t + \nu_j + \epsilon_{ijprcdt}. \end{aligned} \tag{1}$$

The coefficients of interest are β_1, the effect of the quality of the Construction Head on the project, β_2, the effect of the quality of the Project Head on the project, and β_3, the effect of the interaction of both Construction and Project Head quality.

Engineer Assignment A concern for our analysis of the role of individual engineers' quality is the endogenous assignment of engineers to projects. If less experienced or lower quality engineers are assigned to more complicated projects, this would bias our results upward—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 are assigned to more com-

[85] We only observe the compensation and the job title, not the rank. Therefore, one can think of the residual as where the employee falls in the rank.

[86] We use a historical project-level construction dataset that spans 1970-2023 (but does not include costs).

[87] We have tried to collect additional data on these engineers via their public LinkedIn profiles, unfortunately these profiles, if we can locate them, are very sparse and do not include rich information on education or experience.

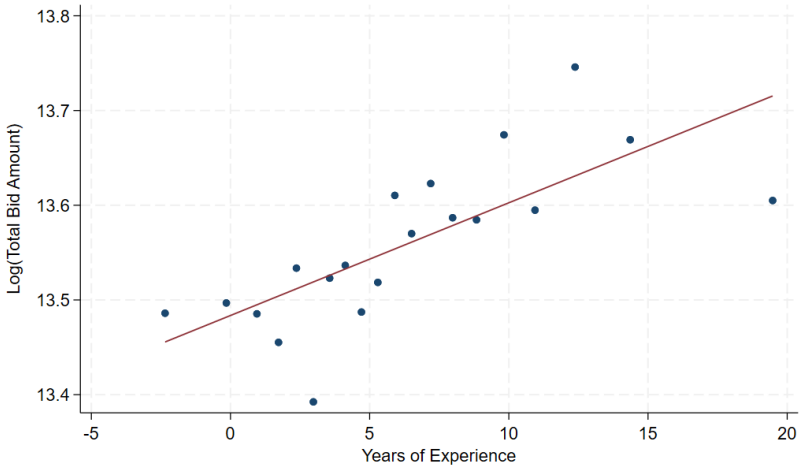
[88] See Appendix K.3 for more information on how we classify project types.

[89] We consider other outcomes—cost overrun and project duration—in Appendix L.

plicated projects. In Appendix K.2, we present evidence from the Caltrans construction handbook and conversations with senior Caltrans officials, which can be summarized with the following quote: "*Managers do not want to assign inexperienced PMs to complex projects.*"[90] Instead, an engineer is assigned to a project based on their experience, as well as the project complexity, type, and location.

Figure 6 shows that more experienced engineers are assigned to more complicated projects, where we proxy complexity with bid size. The underlying assumption is that the higher bid reflects, in part, the fact the project is more difficult and complex to complete. Specifically, the figure shows the relationship between engineer years of experience 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 do our best to control for engineer assignment with project type, county, and route fixed effects. The relationship between total bid and experience persists.

Figure 6: Engineer Assignment to Projects



Notes: The figure shows the relationship between engineer experience and the total winning bid. The figure shows that more experienced engineers are assigned to "larger" projects, where large is measured by the total bid. The binned scatter plot is residualized, controlling for Mileage, Project Type, District, Year, County and Route. Engineer experience is measured in years, using the first year we observe an engineer in the historical construction data as the start year. We can only do this for the Construction Heads; Project Heads are not in the construction data.

4.4 Results

Table 4 shows the results. The outcome of interest is log cost per mile. Engineer quality is standardized, with mean zero and unit variance. All results include district and year fixed effects, while Columns (4)-(6) add project controls (project type, project mileage, and an interaction of type and mileage), and Columns (7)-(9) add county and route fixed effects. County and route fixed effects lead to a slight decrease in the sample size, due to singletons and missing data, but allow us to control for

[90]The terminology Caltrans uses is Project Manager, so PM here refers to the Project Head.

Table 4: Engineer Quality and Project-Level Costs

	log(Cost per Mile)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Construction Head Quality	-0.05		-0.04	0.03		0.03	-0.01		-0.01
	(0.05)		(0.05)	(0.04)		(0.04)	(0.04)		(0.04)
Project Head Quality		-0.11**	-0.11**		-0.11***	-0.11***		-0.11**	-0.11**
		(0.05)	(0.05)		(0.04)	(0.04)		(0.04)	(0.04)
$\text{Quality}_{\text{CH}} \times \text{Quality}_{\text{PH}}$			-0.04			-0.05*			-0.05+
			(0.04)			(0.03)			(0.03)
Adj. R-squared	0.03	0.04	0.04	0.44	0.45	0.45	0.46	0.46	0.46
Observations	1,733	1,733	1,733	1,733	1,733	1,733	1,687	1,687	1,687
District, Year FE	×	×	×	×	×	×	×	×	×
Project Characteristics				×	×	×	×	×	×
County, Route FE							×	×	×

Notes: The table presents the results of estimating Equation 1. Columns (1) - (3) only include district and year fixed effects. Columns (4)-(6) add project characteristics: mileage, project-type dummies, mileage × project type interactions, a zero mileage dummy, and an indicator for the seniority of the Construction Head. Columns (7) - (9) add the county and route fixed effects. The outcome and quality variables are winsorized at the 1% level. Quality for both the Construction Head (CH) and Project Head (PH) are standardized to have mean zero and unit variance. Appendix L provides more details on our quality measure. Robust standard errors reported in parentheses. Appendix Table L.3 presents results for duration and cost overrun outcomes. Appendix Table L.4 reports results clustering at the district level, using wild bootstrap clustering methods. ***p < 0.01, **p < 0.05, *p < 0.1, +p < 0.15

county-level characteristics such as density, and route-level characteristics, such as road roughness. Further, district managers sometimes assign engineers by county and route.

The quality of the Project Head is strongly negatively correlated with costs. A one standard deviation increase in the quality of the Project Head is associated with a 11% decrease in cost per mile.[91] Independently, Construction Head quality does not seem to affect realized costs. However, the interaction of Project and Construction Head quality is also negative.[92] This is striking: the quality of the Construction Head reduces costs when the Project Head is also of high quality. This suggests important complementarities across project phases, akin to an O-ring theory of public goods provision (Kremer, 1993). In effect, the Construction Head is constrained by the project planning and bid-letting phases that occur before construction begins. For example, if the plans are incomplete, the Construction Head cannot do much to prevent change orders and delay, as the project was not well-specified at the start. If instead, the winning bid is high because of a lack of competition, the Construction Head can only manage costs in excess of the bid, not bring the cost any lower than had already been contracted.

The Project Head role has a wide scope—they oversee the planning, design, and bidding process—

[91] Going from the 25th to 75th percentile of engineer quality is associated with a 14% reduction in costs. As a comparison, Best et al. (2023) find that a one standard deviation increase in the performance of Russian procurement officers would reduce prices paid by over 30%.

[92] Appendix Figure L.3 shows that there is no correlation between Construction Head and Project Head quality at the project level.

while the Construction Head only manages the construction process. We find a negative effect of Construction Head quality on cost overruns (Appendix Table L.3)—a one standard deviation increase in Construction Head quality decreases cost overruns by 0.82-0.87 percentage points. The average cost overrun in this sample is 7.77%; high-quality Construction Heads help reduce overruns by about 10-11%. This amounts to a small effect on total costs, given the modest average overrun.[93]

The qualitative evidence from the survey provides some useful context for interpreting the quality results (see Section 3.2). As a summary, both DOT officials and contractors cite issues with DOT engineers stemming from a lack of experience and knowledge base. This can lead to issues in planning ("*they send the project out to bid even though its missing a lot of details*"), during bid letting ("*unfamiliar with what the plans & specs require*"), and in the field ("*hesitant to make simple decisions*"). Many responses cite a high variance in quality (simply put, "*some are really good and some are pretty bad*"), which can even affect participation into projects (i.e., firms avoid working with certain engineers).[94] The results are also consistent with a historical perspective; many attributed Robert Moses' success in obtaining federal funding for New York City's public works projects to his team of highly trained engineers who were able to produce a higher quantity and quality of project plans.[95]

In Appendix Figure L.4 we show how the quality result differs throughout the project cost distribution, by plotting the estimates of the quantile regression from the 5^{th} to 95^{th} percentile. While it could be that higher-quality engineers are only important for managing costs on very large complex projects, we do not find that to be the case. The result is remarkably stable throughout the distribution—with similar effects at the 25th and 95th percentiles.

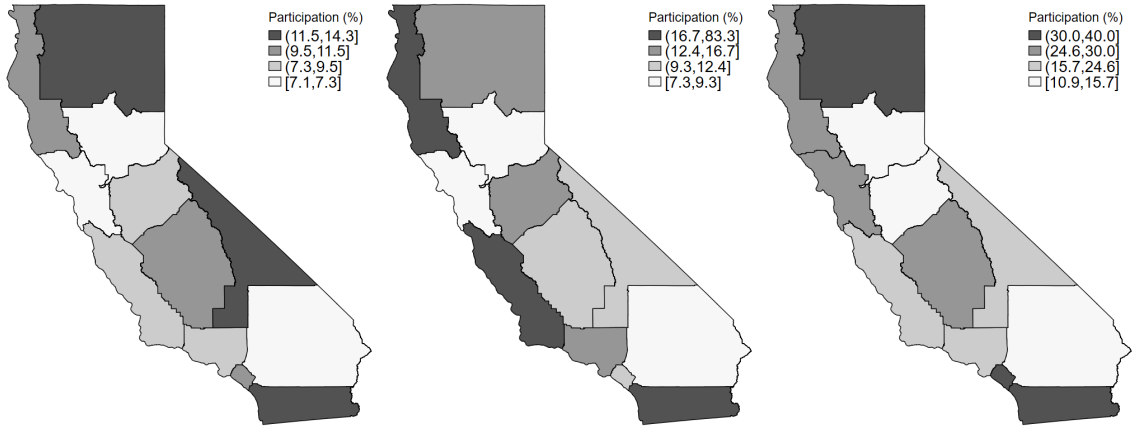
Quality and Competition The effort of the Project Head can also influence the level of competition for the project directly, e.g., by reaching out to potential bidders in advance of auctions. Survey respondents emphasized the role of competition in driving costs and we find that practices such as bidder outreach are negatively correlated with costs across states (Figure 3). We can study how the effect of engineer quality varies with the level of competition in the market. Unfortunately, we do not have data on the number or identity of bidders for the majority of the sample. We have data on

[93]The effect of the Project Head is also negative and statistically significant—a one standard deviation increase in the quality of the Project Head is associated with a 0.73-0.77 percentage point decrease in cost overruns.

[94]For example, one contractor writes: "*Based on past experience we may not bid on projects in areas where there is difficulty working with the representatives whether DOT or consultants.*"

[95]From Caro (1975) (p. 453-454): "by 1936, New York City was receiving one-seventh of the WPA allotment for the entire country... and the Mayor knew who was responsible... Other municipalities were so unequal to the task of planning public works programs of size that in October 1938 the WPA would cancel more than one hundred major grants approved for eleven northeastern cities three years before—because the blueprints for those projects were still not ready. But Moses' engineers would come walking up the front steps of City Hall with blueprints piled high in their arms."

Figure 7: Varying Levels of Bidder Participation in Caltrans Auctions



(a) Road Resurfacing (b) Road Rehabilitation (c) Road Widening

Notes: This figure shows the variation in bidder participation across markets. A market is defined as a project type-district pair. California is divided into 12 districts, as shown in the maps. Each map represents a different project type: (a) Road Resurfacing, (b) Road Rehabilitation, and (c) Road Widening. The darker shading represents more participation, i.e., a higher share of potential bidders actually submit bids to the auction.

bidders for a subsample of years, and use it to calculate the level of competition that the DOT might *expect* for a given project, instead of the realized level of competition for each project in the data.

Our first measure of competition is the number of potential bidders in each "market," which we define as a project type-district pair.[96] For example, the potential bidders for road resurfacing projects in District 1 would consist of the set of firms that ever bid on a road resurfacing project in District 1 (this definition of potential bidders has been used in the literature, see, for example, Hendricks et al., 2003).[97] Of course, some of the variation in the number of potential bidders reflects smaller markets and less demand from the District. As a second definition, we control for the size of the district—the number of potential bidders is divided by the total number of projects completed by the district. The last measure is on the intensive margin—we use the subsample bidding data to calculate the average number of bids on each project in the market and then divide that by the number of potential bidders. We think of this as a measure of participation: how many potential bidders enter the competition for a project, on average. This measure is of particular interest because it is likely something the engineer can affect. Figure 7 shows how participation varies, across districts and project types.[98] Importantly, all three of these measures of competition exhibit variation across

[96] Caltrans splits the state into 12 geographic districts. Each has its own office and management team.

[97] In other auction papers, authors use the number of "plan holders" as the measure of potential bidders (e.g., Bhattacharya et al., 2014; Krasnokutskaya and Seim, 2011; Li and Zheng, 2009). These are settings when the author can observe the number of firms that purchase the project plans ahead of the bidding. We do not observe this in our data (and, as a further complication, only observe bidding for a subset of years of the data). Also, most DOTs only require the purchase of plans for larger scale construction projects.

[98] Appendix Figure K.1 shows the variation for potential bidders.

Table 5: Heterogeneous Effects of Quality and Competition

	log(Cost per Mile)				
	(1)	(2)	(3)	(4)	(5)
Project Head Quality	-0.11**	-0.05	-0.11*	-0.05	-0.11**
	(0.05)	(0.08)	(0.06)	(0.05)	(0.05)
× Potential Bidders < Median		-0.12			
		(0.10)			
× $\frac{\text{Potential Bidders}}{\text{District Size}}$ < Median			-0.00		
			(0.10)		
× Bidder Participation < 10%				-0.19*	
				(0.11)	
× Emergency Project					-0.03
					(0.20)
Project Chars, District, Year, County FE	×	×	×	×	×
Adj. R-squared	0.45	0.45	0.45	0.45	0.45
Observations	1,699	1,699	1,699	1,699	1,699

Notes: The table presents the results of estimating Equation 1, but adds interactions with market or project-level characteristics and clusters standard errors at the market (project type × district) level. All specifications include project characteristics and district, year and county FE (it does not include route FE, leading to more observations than Table 4). Column (1) shows the baseline effect. Column (2) interactsProject Head Quality with an indicator for whether the market has fewer than median potential bidders, within that project type. Column (3) repeats this, but normalizes the number of potential bidders by the size of the district (number of projects). Column (4) includes an interaction for whether the market is "low participation," which means that the average number of realized bidders is less than 10% of the potential bidders (41% of projects). Finally, Column (5) includes an interaction for whether the project was under an "emergency contract" (only 15% of projects in the sample are emergency contracts). The quality of the Project Head is standardized with mean zero and unit variance. The sample is restricted to markets with observations in the bidder sample, which leads to a slight decrease in sample size. ***p < 0.01, **p < 0.05, *p < 0.1, +p < 0.15

project types within districts, which means that the same Project Head can be exposed to more or less competitive markets.

Table 5 shows how the effect of quality varies with the level of competition in the market. Column (1) reproduces the baseline result from Table 4. Column (2) adds an interaction for whether the market (project type-district pair) has fewer potential bidders than the median market, where the median is defined within a project type. Column (3) repeats the exercise, with the potential bidders per project measure. Column (4) uses the participation variable, with a cut-off of 10% of potential bidders participating. Finally, Column (5) examines the interaction of quality with emergency contracts, which generally do not have normal competitive bidding procedures.[99]

[99]Emergency contracts are usually awarded without a competitive bidding process. From the Caltrans website: "*Caltrans uses emergency contracts when services or goods are needed to immediately respond to 'a sudden, unexpected occurrence that poses a clear and imminent danger requiring immediate action to prevent or mitigate the loss or impairment of life, health, property, or essential public services' as provided by Public Contract Code Section 1102. Caltrans Districts obtain the required approvals for emergency work and select contractors to perform emergency work under Emergency Force Account and Emergency Limited Bid contracts. Contractor selection is based on several factors such as, proper licensing and registrations, ability, proximity to the damage, willingness to mobilize quickly, or by lowest bid. Caltrans maintains a list of potential contractors available for emergency work.*" See `https://dot.ca.gov/programs/civil-rights/emergency-contracts` for more.

A priori, it is not obvious that high-quality engineers would be more effective in less competitive markets. A lack of competition can lead to higher bids, and therefore higher costs, despite the best efforts of the engineer. Conversely, competition may discipline bids such that quality in developing plans and communicating with contractors is not as important. Strikingly, the largest effect we find is for the bidder participation variable. Here, it is more straightforward how engineer quality and effort would matter: high-quality Project Heads develop good relationships with bidders and do outreach to get them to participate in the auctions they manage. In markets where there are many potential bidders, but few actually participate in the average auction, the Project Head can move the needle on competition by increasing participation for their projects.

5 Retirements and Costs

In this section, we use panel variation in engineer retirements by district as a quasi-experimental capacity "shock." This will allow us to quantify how the loss of experience (quality) translates to costs, at a more aggregate level.

Past work has studied how employee departures affect productivity, though largely through the lens of increased workload.[100] We are not only interested in how retirements affect employee workload; we are interested in the loss of institutional knowledge that departs the district with the retirement.[101] 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 decrease. Therefore, we study the direct effect of retirements on district-level project outcomes.

5.1 Empirical Approach

We construct a retirement shock: the share of engineers that retire in each district-year. The numerator is the number of retirements in the district-year. The denominator is slightly more complicated because we do not have district level 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.[102] Appendix Figure M.1 shows the distribution of retirement shocks—the mean is

[100] 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.

[101] We do not use retirements as an IV for employment (unlike Warren (2014) and Giuffrida and Raiteri (2023)). Instead, we are interested in plausibly exogenous shifts in district employee quantity *and* quality, similar to Decarolis et al. (2020).

[102] Ideally, our base year would be 2000, but we use 2011 because it is the first year for which we have access to employment records. We have statewide employment of engineers, so we also have to adjust for the fact that not all

2.1% and the standard deviation is 1.7%.[103]

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 cost and duration of projects awarded 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 awarded 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. Y_{dt} measures the mean or median outcome for projects *awarded* in district d and year t. The outcomes of interest include project cost, cost overrun, and duration, each of which we winsorize at the 2% level.

Identification requires that retirements only affect project 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.[104,105] However, project planning (environmental review, permitting, right-of-way), would not have been avoided if the employee retires in the year the project is awarded. Therefore, employees who would have liked to retire to avoid larger projects (or to work on them as a consultant from the private sector) would have needed to retire years before the project is awarded. We study the effect of retirements in t on projects awarded in t, avoiding this potential threat to identification.

5.2 Results

Table 6 shows the results. We first consider the results on "All Engineers," the top row of coefficients. A one percentage point increase in retirements translates to a 4.3% increase in costs at the mean, and a 3.2% effect at the median. For cost overruns, the effect is only statistically significant at the median. The median cost overrun is 4.9% over the districts in Caltrans. Therefore, districts with

engineers are assigned to a district; about 20% work at Caltrans Headquarters.

[103] 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%.

[104] More generally, we assume that there are no time-varying, district-specific, shocks that cause both retirements and more costly projects. We cannot disprove the existence of such a shock but struggle to find a convincing example of such an event in our context.

[105] The 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. In Appendix Table M.2 we show that retirements are not correlated with more or longer projects, or more complicated project types.

Table 6: Engineer Retirements and District-Level Project Outcomes

	log(Total Cost ($))		Cost Overrun (%)		Duration (Days)	
	Mean	Median	Mean	Median	Mean	Median
	(1)	(2)	(3)	(4)	(5)	(6)
			All Engineers			
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	0.043**	0.032+	0.237	0.279**	10.569***	8.076**
	(0.019)	(0.022)	(0.204)	(0.130)	(3.968)	(4.057)
R-squared	0.73	0.71	0.60	0.60	0.69	0.67
			Staff Engineers			
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	0.043**	0.023	0.380*	0.351**	11.735***	7.564*
	(0.020)	(0.021)	(0.224)	(0.144)	(4.437)	(4.395)
R-squared	0.73	0.71	0.60	0.61	0.70	0.66
			Senior Engineers			
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	0.016+	0.019+	-0.065	0.007	2.117	2.079
	(0.010)	(0.013)	(0.087)	(0.063)	(1.890)	(1.988)
R-squared	0.73	0.71	0.60	0.59	0.69	0.66
Observations	228	228	228	228	228	228
District, Year FE	×	×	×	×	×	×
Dep. Var. Mean	13.97	13.80	6.80	4.90	365.53	285.54

Notes: The table presents regressions of the district-level retirement shock on district-level project outcomes (project cost, cost overrun, and duration), 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 not driven by changes in the composition of projects (Appendix Table M.2). Robust standard errors reported in parentheses. Appendix Table M.3 reports results clustering at the district level, using wild bootstrap clustering methods. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15.

a one percentage point increase in retirement shock experience a 5.7% increase in cost overruns.[106] Lastly, 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). These results show that costs and duration increase for projects that are awarded in the same year as the retirements, but we do not find that the results persist for projects awarded in the next year (the effect is positive but not statistically significant).

Table 6 also shows the result by the "type" of retirement. We define two types: "Staff" and

[106]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 there is no need to standardize each project to make them comparable, as long as there is no change in project composition that coincides with retirements. We test for this; there is no effect of retirements on project mileage or number of projects let, or on the composition of projects awarded (Appendix Table M.2).

"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 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 very small, or no, effects. A one percentage point increase in the retirement shock for staff engineers is associated with a 4.3% increase in mean costs, a 0.38 percentage point increase in mean overrun (5.6%), and a 11.7 day increase in mean duration (3.2%). The mean retirement shock for "staff" engineers is 1.7% and the standard deviation is 1.4%.

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 delivering the project—drawing up project plans, creating cost estimates, communicating on the ground with the contractor, and even acting as the Project Head—who 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 that is accumulated with experience on the job, issues finding qualified candidates, and the time it takes to train new hires (see Section 3.2 for more).

The Cost of Retirement We can calculate the total cost, in dollars, of a one percent retirement shock. First, Table 6's results imply a 4.3% average cost increase, which we assume is uniform across projects and districts. The majority of the projects in the dataset are relatively small, so this translates to an increase of $157,000 at the project level on average, but for the largest projects costs can increase by over $1 million. Then, we can aggregate the project-level cost increases to the district; the average district experiences an increase in costs of $6.7 million in a year, with significant variation driven by the composition and number of projects awarded in that year. Finally, we aggregate this to the state level, for a total of $80.4 million in additional spending in the average year.

Is $80 million in additional costs large? Consider the potential cost savings. A one percent retirement shock translates to just under 60 engineers retiring across the state in one year. We conservatively assume that these retiring engineers are at the top of the pay distribution, as they have the most experience and skill. Therefore, we assume that each retiring engineer makes $220,000 in salary and benefits per year, which means that the cost savings to Caltrans is $13.2 million, or about 16% of the total additional costs. Of course, the "cost savings" in forgone salary and benefits

ignores the pension obligations and the cost of hiring new engineers, so the $13 million estimate is likely an upper bound on total savings. (On the other hand, the calculation ignores the fact that some of the retirees are replaced within the year, which adds costs.) In effect, the results suggest that experienced engineers at Caltrans are being paid far below their marginal product (Frank, 1984; Lazear, 1979): there is a 6:1 ratio of savings versus costs from employing these workers.

Simulation Exercise As a sanity check, we benchmark the district-level retirement results against the individual-level engineer quality results. We simulate a 1% retirement shock through each district and year in the sample. We make the following assumptions on the counterfactual replacement for retiring engineers:

1. The retiring engineers would have been assigned to the largest projects (i.e., the projects with the highest winning bids), had they not retired. Figure 6 shows that this is true in the construction data: years of experience is strongly positively correlated with bid per mile.

2. The retiring engineers are replaced by engineers with one standard deviation less experience. In the engineer analysis we estimate that a one standard deviation increase in Project Head quality decreases costs by about 11%, therefore we simulate an increase in costs of 11% for the projects that would have been assigned to the retiring engineers. 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 (on average, this is a difference of 5 years).

We find that under these assumptions, a one percentage point retirement shock would increase total costs by 6.2% at the mean. This is a large effect; which is partly due to the skewness in the project cost data. If we assume instead of the largest project, the retiring engineer would have been assigned to a randomly chosen project in the upper quartile of project size, we predict a 2.8% increase in costs at the district level. Therefore, some of the cost effect in the retirement analysis may be driven by workload effects.[107]

6 Paying for Engineer Quality

The qualitative evidence from the survey and the analyses using Caltrans data provide evidence of the value of engineer quality and, conversely, the cost of losing experience to retirement. Retaining

[107]The fact that we find an effect on duration in the retirement analysis, but not the quality results, is also consistent with workload effects.

high-quality employees and preventing early retirements is therefore one policy that may have a large potential upside on managing costs.[108]

The pension data from Caltrans suggest that many engineers retire soon after the threshold for receiving a pension (50 years of age): the average years of service at retirement is 29 years (Appendix Figure M.2). Anecdotally, many public sector engineers move to the private sector after leaving the DOT, where they are compensated at much higher levels.[109] In response to our survey question about employee quality, contractors cite exactly this phenomenon as the cause of low levels of experience at the DOT: "*The DOT retirement plan allows them to retire early (which most do) and work in the private sector while collecting DOT retirement benefits*" and "*Most of the top performers within the DOT rise quickly and end up in the private market.*" This begs the question—how much would the DOT be willing to pay to retain experienced, high-quality, engineers?

According to our individual-level analysis, a standard deviation increase in engineer quality translates to 11% lower project costs. The amount that Caltrans should be willing to pay to increase quality therefore depends on the level effect of quality on costs and the number of projects a Project Head works on per year. First, consider the effect in levels. Appendix Table L.5 shows that a one standard deviation increase in quality reduces costs by $480,000 per mile. The median project is 3 miles long, so this translates to a cost savings of $1.44 million per project. The Project Heads in our sample work on 0.52 projects per year, at the median (0.65 at the mean).[110] Therefore, a one standard deviation increase in quality is worth $749,000 in cost savings, per engineer-year, to the DOT. If we are more conservative about workload—i.e., suppose Project Heads work on one project every three years instead of every two years—a one standard deviation increase in quality would save the DOT $475,000 per engineer-year.

In contrast, the average Project Head in our sample makes $154,000 in salary and benefits (the av-

[108]This the strategy that Robert Moses used to hire his team of highly skilled government engineers, which then allowed him to obtain extensive federal funding (discussed in Section 4). For instance, Moses confronted the Civil Works Administration in 1934 and convinced them to remove some of their labor regulations for him—"[Moses] must be allowed to hire the best architects and engineers available and he must be allowed to hire them fast... And the agency must drop its rule that no worker could be paid more than thirty dollars per week... After seven days of haggling, the CWA surrendered. Moses was given permission... to pay them up to eighty dollars a week." (Caro, 1975, p. 369).

[109]We know this from survey responses, internal DOT reports (GAO, 2008; TxDOT, 2010), conversations with DOT officials, and online message boards about state employment. See Appendix N for more.

[110]We try to be as conservative in creating this measure of projects per year. We use the Caltrans project delivery dataset, which has dates for the project planning phases and construction. We assign the first year of any planning phase as the first year the Project Head is in our sample, and then we take the last year of construction as the last year they are in the sample. This range serves as the denominator (i.e., a proxy of the number of years the engineer is working as a Project Head), and the numerator is the number of projects they are attached to in our data. Then we drop the engineers in the 95th percentile of number of projects. This gives us a median of 0.52 and mean of 0.65, as reported in the text. If we do not drop the 95th percentile engineers, we arrive at a median of 0.55 and a mean of 0.78. If we only consider Project Heads with a larger than median average project size, the statistics are similar: 0.50 at the median and 0.64 at the mean. This falls to a median of 0.47 and a mean of 0.56 when we drop the 95th percentile.

erage salary is $116,000). The Project Heads at the very top of the distribution—the 99$^{\text{th}}$ percentile—make between $196,000 and $216,000. This means that the cost saving that is delivered by a standard deviation *increase* in engineer quality is worth more than two to three times their annual compensation.

In California, median salaries for civil engineers in the state government are at par with the private sector (CalHR, 2023). However, the wages at the top of the distribution can be quite different (Appendix Figure N.1).[111] A senior-level private-sector civil engineer in California can earn between $210,000 and $380,000—compared to a maximum Senior Transportation Engineer salary of $168,000 at Caltrans ($216,000 with benefits, per CalHR, 2025).[112] Therefore, Caltrans should be willing to offer high-quality employees the private-sector wage. This would clearly save the agency money: if the retained employee is just one standard deviation more experienced than their replacement, this results in a cost savings between $475,000 and $749,000 per year, at a salary increase of between $42,000 and $212,000.

Given the potential cost savings, why do state DOTs not pay high-quality engineers more? Mas (2017) studies a 2010 California law that mandated the online posting of city employee salaries. This led to wage compression and increased turnover of the top paid city managers. He argues that the effects are consistent with public aversion to high salaries, which may be a relevant factor in our setting as well. Generally, wage compression in the public sector, and increased wage inequality in the private sector, can cause difficulties in hiring and retaining skilled workers in government (Borjas, 2002; Katz and Krueger, 1991).[113]

7 Conclusion

In this paper, we demonstrate how state capacity shapes infrastructure delivery in the United States, with a focus on the skill and experience of government engineers. In this sector, state governments plan projects and then hire private firms to execute them. We start by collecting novel data on project costs in all 50 states, and then complement this new data with survey evidence on cost drivers. Survey respondents agree that state government capacity is an important cost driver, and link capacity to

[111] Appendix Figure N.1 shows the distribution of income for civil engineers working in the private sector and in state government. The figure suggests that wage compression is a feature across states, not only in California.

[112] The data on private sector salaries comes from `Indeed.com`. This is only salary, not benefits.

[113] Katz and Krueger (1991) document an increase in private sector wage inequality in the 1980s, but no such change for the public sector. They posit multiple theories for public sector pay rigidity, but do not find any one that explains it in full. They also show the federal government has difficulty retaining high-skill employees. Borjas (2002) shows that as wage inequality in the private sector grew between 1970-1990, high-skilled workers in the private sector were less likely to leave for the public sector, while high-skilled public sector workers were more likely to leave for the private sector.

the competence of individual government engineers, especially highly experienced ones. Our survey responses allow us to understand *how* government engineers matter: producing accurate project plans, avoiding costly change orders, and performing outreach to potential bidders.

Motivated by these findings, we use detailed personnel data from the state of California to quantify the role of individual government engineers. The quality of the Project Head, the government employee responsible for managing the entire project, is strongly associated with lower costs. Next, we quantify the effect of retirements of experienced engineers on costs. Potential payroll savings from encouraging retirements are dwarfed by the increase in costs from the reduction in capacity; the government should be willing to pay much more to retain skilled and experienced employees. And governments should be especially cautious about cumbersome hiring and promotion rules that make it more challenging to hire and retain high-quality engineers.

The issue of retaining high-skill employees in government is not a new one. As wage inequality began to rise in the private sector in the 1970s, wages in the public sector were slow to respond, leading to relative wage compression (Borjas, 2002; Katz and Krueger, 1991). Further, policy choices by multiple administrations led to a downsizing of government workforces as a share of the population or in absolute numbers, which resulted in an increased reliance on private sector consultants (for example, Clinton's Federal Workforce Restructuring Act of 1994). In the states, balanced budget requirements have caused agencies to freeze hiring or wages during recessions (Gordon, 2012; Sherman and Lane, 2009). Our results suggest that these cost saving measures may instead actually lead to increases in the cost of public service delivery.

State capacity is a fundamental issue across the world (Besley and Persson, 2010). In the U.S., the scope of what government does is vast, and relatively few government employees manage the work. For infrastructure, we show that increasing the quality and quantity of the workforce can pay for itself. More generally, relatively weak government capacity may play an important role in explaining why it costs so much to build infrastructure in the U.S., compared to more robust institutions in Europe (Goldwyn et al., 2023; Kagan, 2001; Wilson, 1989).

There are many examples of burdensome administrative hurdles and regulations preventing efficient implementation of government policy (Klein and Thompson, 2025; Pahlka, 2023). In our setting, we find that "more" government, in the form of more and more experienced employees, is needed to efficiently deliver public goods. Further work should explore the relationship between state capacity and regulation. Qualitative evidence from our survey suggests that the numerous rules governing engineers and infrastructure delivery at state agencies help explain why institutional experience is so valuable—and why its loss can be so costly.

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Appendix

A Hypotheses: DOT Planning, Procurement, and Project Delivery

In this section we provide more details on the state DOT planning, procurement, and project delivery process. For the remainder of this section we will simplify by calling it the "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. Our survey also allows us to highlight cost drivers that have not been studied much in existing literature. For example, we 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 Planning

In the first stage, planning, the procuring entity (the state DOT) assesses its 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 and develops detailed plans. State DOTs often plan highway construction projects four 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; further, 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.[114] 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. 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.

[114] 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).

Efforts to increase the bidder pool can decrease costs.

Advertising the project and doing outreach to potential bidders can have substantial effects on the 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 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. Figure A.1 shows an example of unit bidding.

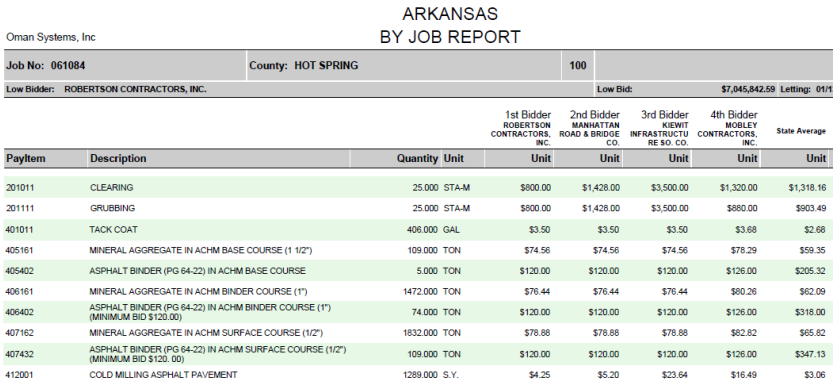
Strict criteria to evaluate bids have the potential to decrease costs.

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's 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. 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.

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.

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.

Delays can increase total project costs, and incur costs to commuters who would like to travel on the road that is being serviced. What is not as well established is 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.[115] Recent work in the Kenyan setting shows 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.

[115] 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 that of a contractor that was unaware of the regulatory changes (Tarrer and Boylan, 1995).

B Example Project

In order to give the reader some additional context, we go through 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. The construction team needs to level the highway (grading), remove the top layer of an existing asphalt (bituminous) road using a milling machine (bituminous mill), and apply a fresh layer of asphalt (overlay). Figure B.2 shows a snapshot of the process. Although this is a very small project compared to bridge or subway construction, it is still relatively capital intensive.

As we described in Section 2.2.1, the state DOT plans the project, publishes those plans and a bid document for the contractor to fill out, and then evaluates the bids. 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 have, either from the data we requested from the DOT, or from the supplemental information we collected from online searches of bid documents. Figure B.3 further shows a snapshot of the project plans, which would also be included in the bid document. For this project, the bid document is 345 pages long.

Figure B.1: First Page of Bid Document

MINNESOTA DEPARTMENT OF TRANSPORTATION
395 JOHN IRELAND BOULEVARD MS 650 ST. PAUL, MINNESOTA 55155-1800
********** PROPOSAL **********
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 each submitted 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 collected from MNDOT, was $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

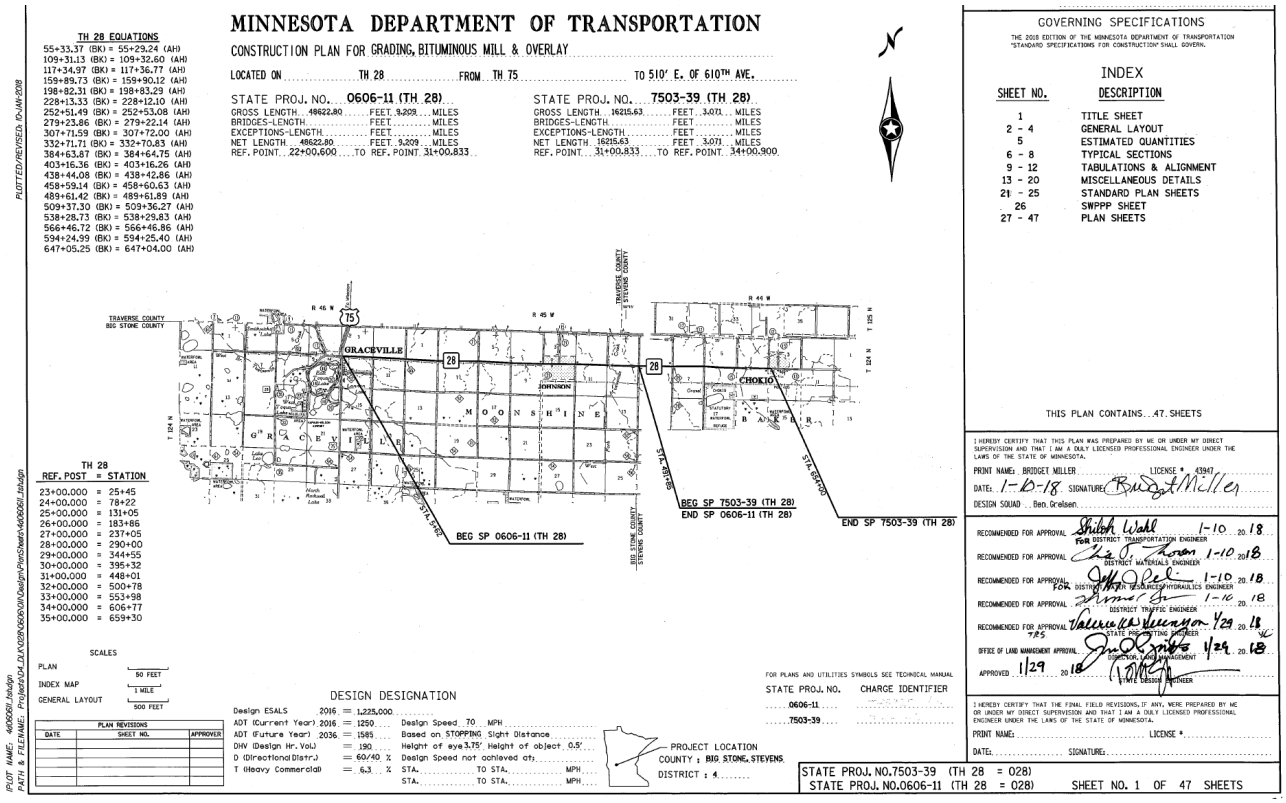


Figure B.4: Snapshot of Unit Bids

Minnesota Department of Transportation

Contract Schedule Page 1 of 5

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		Bid Amount	
			Dollars	Cents	Dollars	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 Example Change Orders

A change order is an ex post change to the original contract between the bidder (contractor) and the DOT. The contract is an official document signed by both parties, which includes the plan of work and quantities of input, as specified by the DOT, and the price of each input that the DOT will pay to the contractor, as specified by the unit bids.

Deviations from the contract can arise during the construction phase. This includes, for example, additional work that is needed to be performed in order to complete the project. The change order can necessitate a change in quantity, a change in materials, or a change in the unit price.

Caltrans has a "Change Order Examples" webpage with examples to assist their engineers in filing change orders. (See `https://dot.ca.gov/programs/construction/change-order-information/change-order-examples` for more.) They categorize the change order examples into possible reasons for a change order, which include but are not limited to: "Change Material Specifications," "Increase in Bid Item Quantities," "Differing Site Condition," "Item Adjustment," and "Item Increase/Decrease and Extra Work."

Figure C.1 shows two examples. Figure C.1(a) describes extra work needing to be done due to "differing site conditions." In this case, the Contractor encountered subsurface rock when excavating a structure, and thus additional work needed to be done, at an additional cost of $12,000. Figure C.1(b) describes additional work and a change in materials—the associated memo describes an issue with the pre-specified material (i.e., the material specified in the project plans). Because the pre-specified material was not functioning well, it needed to be replaced (the contractor had to redo the work with the new material). This is associated with a cost increase of $404,250.

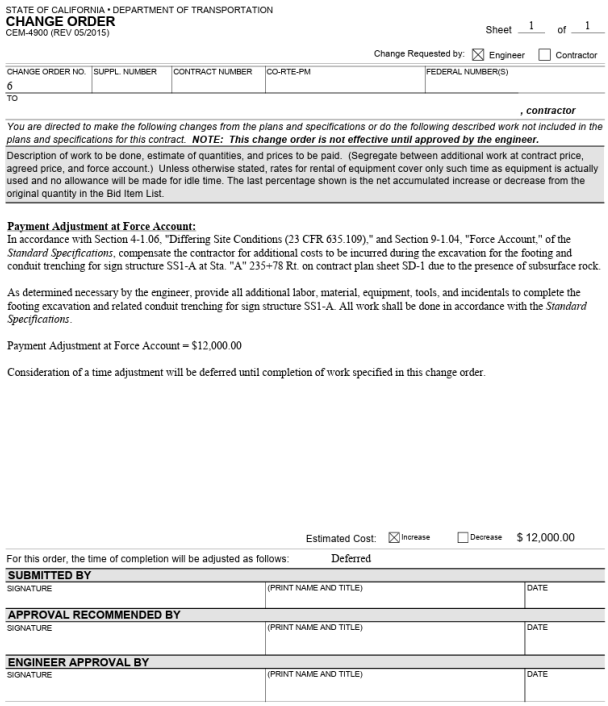
Another example change order describes multiple changes to the project, due to small mistakes in the project plans:

> "1) Installing two additional sections of each type of HMA Dike (Type A and Type C). After consulting with the project engineer, it was confirmed these four sections of cut slope dike were accidentally omitted from project plans. The work will be paid by increasing the respective bid item quantity. 2) Adding three sections of HMA Dike (Type F). After consulting the project engineer, it was confirmed the mountable dike was not included in the project plans. This work will be paid as extra work at agreed unit price since there is no applicable bid item. 3) Deleting four sections of planned HMA Dike (Type E). Dikes at these locations are not necessary because they are located on the high side of the roadway super. This deletion will be credited by decreasing the bid item quantity. 4) Adding three HMA overside drains with rock energy dissipators. For each section of added HMA Dike (Type F), an overside drain at their respective low points is necessary to transfer water from the dike to the adjacent ditch. This work will be paid as extra work at agreed lump sum since there are no applicable bid items."

Another example cites a change order due to unresolved right-of-way issues:

"Before the project was advertised, the district right-of-way agents were unable to close negotiations with abutting property owner adjacent to Station 782+32. An Order of Immediate Possession was obtained so that construction could begin. Before the start of construction, negotiations finally closed. The major item of agreement was the construction of an 8-foot x 8-foot reinforced concrete box culvert, located at Station 782+32, to serve as a cattle pass from one portion of the property to the other."

Figure C.1: Example Change Orders



STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION
CHANGE ORDER
CEM-4900 (REV 05/2015)

Sheet 1 of 1

Change Requested by: ☒ Engineer ☐ Contractor

CHANGE ORDER NO.	SUPPL. NUMBER	CONTRACT NUMBER	CO-RTE-PM	FEDERAL NUMBER(S)
6				

TO , *contractor*

You are directed to make the following changes from the plans and specifications or do the following described work not included in the plans and specifications for this contract. ***NOTE: This change order is not effective until approved by the engineer.***

Description of work to be done, estimate of quantities, and prices to be paid. (Segregate between additional work at contract price, agreed price, and force account.) Unless otherwise stated, rates for rental of equipment cover only such time as equipment is actually used and no allowance will be made for idle time. The last percentage shown is the net accumulated increase or decrease from the original quantity in the Bid Item List.

Payment Adjustment at Force Account:
In accordance with Section 4-1.06, "Differing Site Conditions (23 CFR 635.109)," and Section 9-1.04, "Force Account," of the *Standard Specifications*, compensate the contractor for additional costs to be incurred during the excavation for the footing and conduit trenching for sign structure SS1-A at Sta. "A" 235+78 Rt. on contract plan sheet SD-1 due to the presence of subsurface rock.

As determined necessary by the engineer, provide all additional labor, material, equipment, tools, and incidentals to complete the footing excavation and related conduit trenching for sign structure SS1-A. All work shall be done in accordance with the *Standard Specifications*.

Payment Adjustment at Force Account = $12,000.00

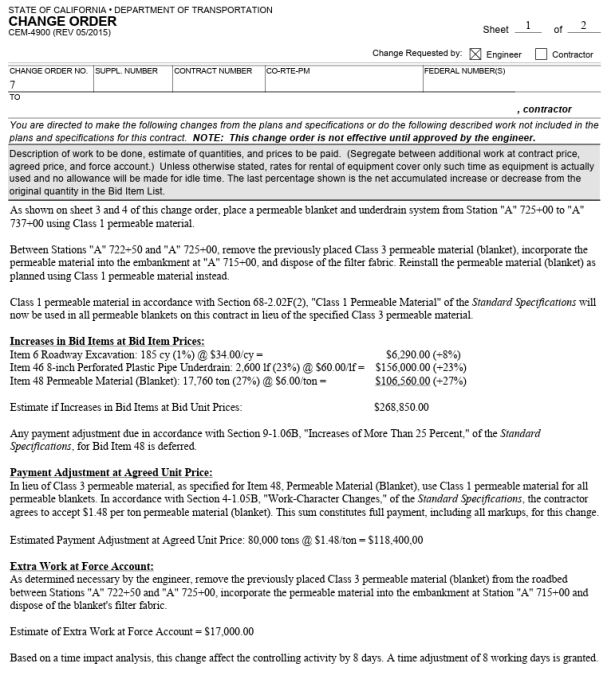
Consideration of a time adjustment will be deferred until completion of work specified in this change order.

Estimated Cost: ☒ Increase ☐ Decrease $ 12,000.00

For this order, the time of completion will be adjusted as follows: Deferred

SUBMITTED BY		
SIGNATURE	(PRINT NAME AND TITLE)	DATE
APPROVAL RECOMMENDED BY		
SIGNATURE	(PRINT NAME AND TITLE)	DATE
ENGINEER APPROVAL BY		
SIGNATURE	(PRINT NAME AND TITLE)	DATE

(a) Differing Site Condition



STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION
CHANGE ORDER
CEM-4900 (REV 05/2015)

Sheet 1 of 2

Change Requested by: ☒ Engineer ☐ Contractor

CHANGE ORDER NO.	SUPPL. NUMBER	CONTRACT NUMBER	CO-RTE-PM	FEDERAL NUMBER(S)
7				

TO , *contractor*

You are directed to make the following changes from the plans and specifications or do the following described work not included in the plans and specifications for this contract. ***NOTE: This change order is not effective until approved by the engineer.***

Description of work to be done, estimate of quantities, and prices to be paid. (Segregate between additional work at contract price, agreed price, and force account.) Unless otherwise stated, rates for rental of equipment cover only such time as equipment is actually used and no allowance will be made for idle time. The last percentage shown is the net accumulated increase or decrease from the original quantity in the Bid Item List.

As shown on sheet 3 and 4 of this change order, place a permeable blanket and underdrain system from Station "A" 725+00 to "A" 737+00 using Class 1 permeable material.

Between Stations "A" 722+50 and "A" 725+00, remove the previously placed Class 3 permeable material (blanket), incorporate the permeable material into the embankment at "A" 715+00, and dispose of the filter fabric. Reinstall the permeable material (blanket) as planned using Class 1 permeable material instead.

Class 1 permeable material in accordance with Section 68-2.02F(2), "Class 1 Permeable Material" of the *Standard Specifications* will now be used in all permeable blankets on this contract in lieu of the specified Class 3 permeable material.

Increases in Bid Items at Bid Item Prices:

Item 6 Roadway Excavation: 185 cy (1%) @ $34.00/cy =	$6,290.00 (+8%)
Item 46 8-inch Perforated Plastic Pipe Underdrain: 2,600 lf (23%) @ $60.00/lf =	$156,000.00 (+23%)
Item 48 Permeable Material (Blanket): 17,760 ton (27%) @ $6.00/ton =	$106,560.00 (+27%)

Estimate if Increases in Bid Items at Bid Unit Prices: $268,850.00

Any payment adjustment due in accordance with Section 9-1.06B, "Increases of More Than 25 Percent," of the *Standard Specifications*, for Bid Item 48 is deferred.

Payment Adjustment at Agreed Unit Price:
In lieu of Class 3 permeable material, as specified for Item 48, Permeable Material (Blanket), use Class 1 permeable material for all permeable blankets. In accordance with Section 4-1.05B, "Work-Character Changes," of the *Standard Specifications*, the contractor agrees to accept $1.48 per ton permeable material (blanket). This sum constitutes full payment, including all markups, for this change.

Estimated Payment Adjustment at Agreed Unit Price: 80,000 tons @ $1.48/ton = $118,400,00

Extra Work at Force Account:
As determined necessary by the engineer, remove the previously placed Class 3 permeable material (blanket) from the roadbed between Stations "A" 722+50 and "A" 725+00, incorporate the permeable material into the embankment at Station "A" 715+00 and dispose of the blanket's filter fabric.

Estimate of Extra Work at Force Account = $17,000.00

Based on a time impact analysis, this change affect the controlling activity by 8 days. A time adjustment of 8 working days is granted.

(b) Change in Materials

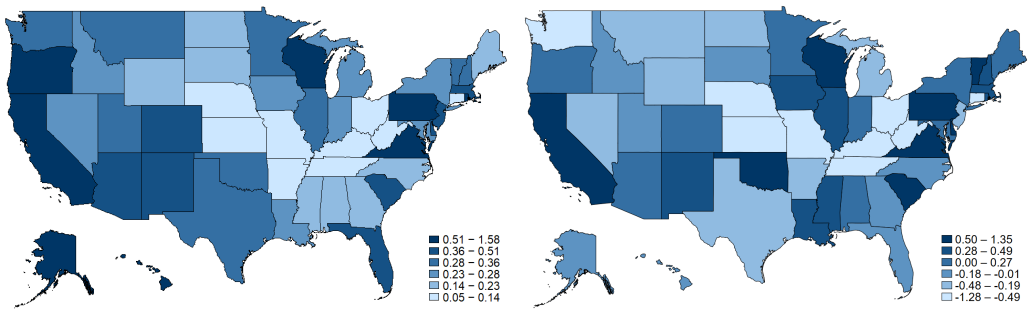
D Cost Data

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

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 shows the distribution of cost per mile across states, while Figure D.2 shows the distribution of costs per mile, total cost, and mileage, at the project level. Figure D.3 shows the spending and length of the projects across space. Figure D.4 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.5 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, therefore we can treat current construction costs as realized costs. The two objects have a correlation coefficient of 0.99. Our final sample uses the realized cost or current contract cost when available (35 states), and the winning bid for the remainder (15 states). As a final exhibit, Figure D.6 shows the correlation between the costs and the duration of the project.

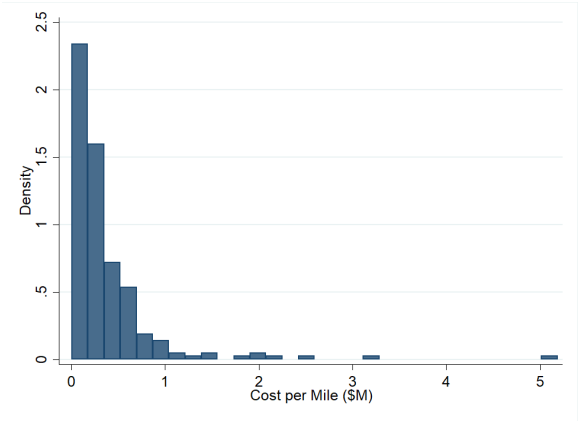
Figure D.1: Resurfacing Costs per Mile ($M) across States



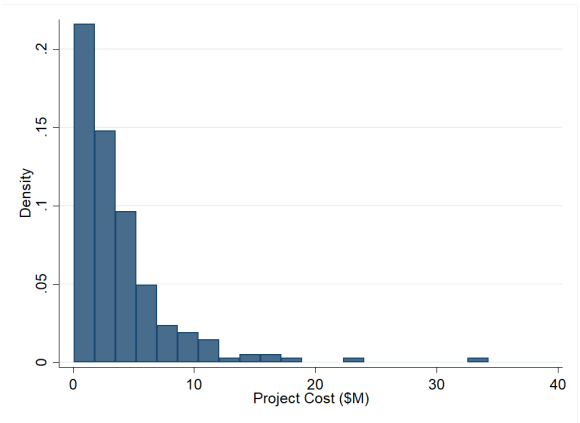
(a) State-Level Cost per Mile ($M) (b) State-Level Residual Cost per Mile

Notes: The figure on the left takes the average of project cost per mile at the state level. 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 mile on the observables included in Column (2) of Table 1. There are 250 projects in the sample: 5 projects per state.Data collected by the authors.

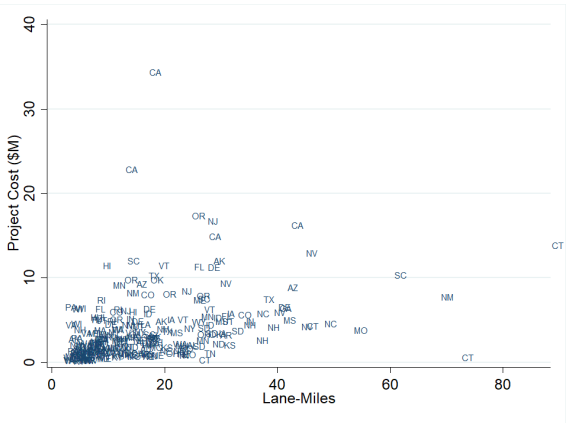
Figure D.2: Project-Level Costs($M) and Mileage



(a) Project-Level Cost per Mile



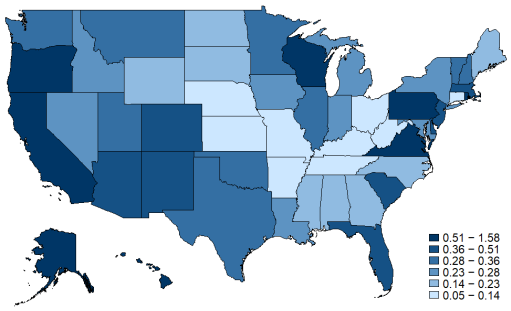
(b) Project-Level Total



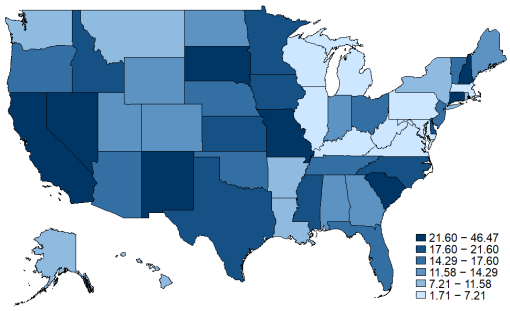
(c) Total vs Mileage

Notes: The top figure (a) shows the histogram of project-level resurfacing costs per mile. There are 250 projects in the sample: 5 projects per state. The histogram on the left (b) shows the distribution of project-level costs in the data collected by the authors. The scatter plot on the right (c) takes each project cost and plots it against total mileage of the project (in lane miles).

Figure D.3: Spending and Project Characteristics



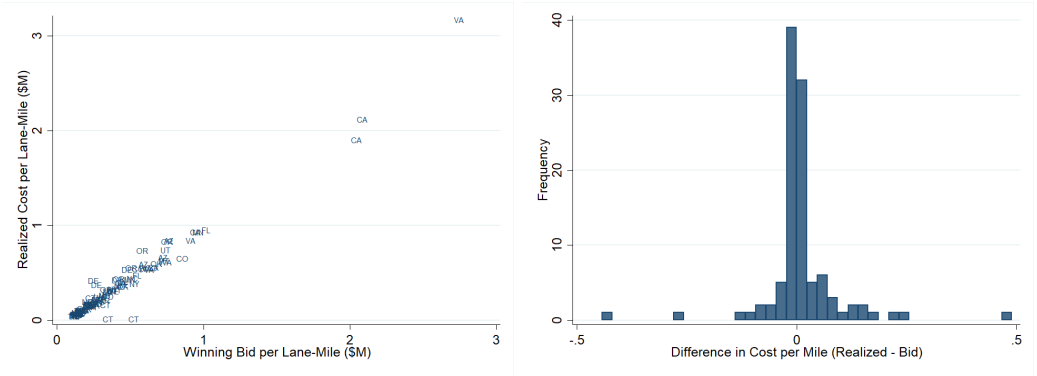
(a) State-Level Spending



(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 D.2 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.

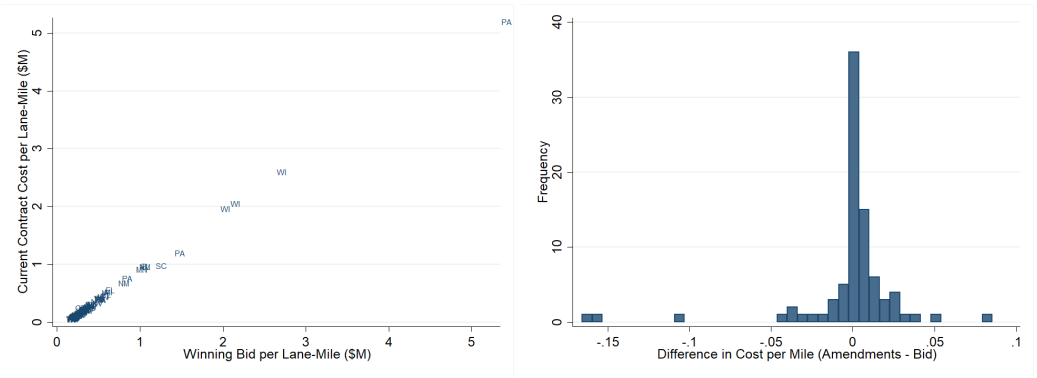
Figure D.4: Bids vs Realized Costs



(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.

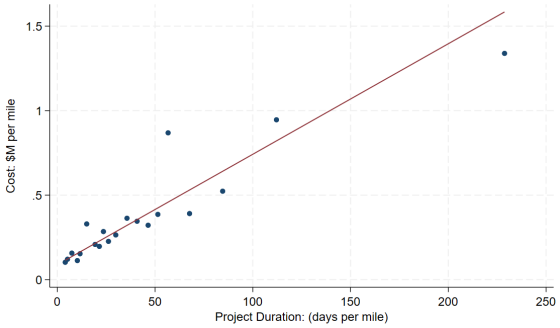
Figure D.5: Bids vs Amended Contracts



(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.

Figure D.6: Costs and Project Duration

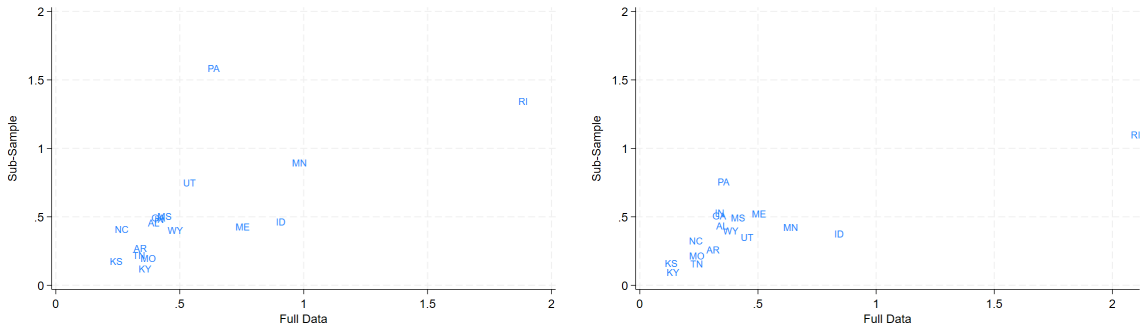


Notes: This is a binned scatter plot of project-level costs and duration. The y-axis shows the cost per mile, in $M. The x-axis shows the duration per mile, in days. The data was collected by the authors, as part of the project-level cost data. The project duration variable is only available for 33 states.

D.1 Comparing Our Subsample to All Available Data

We use a subsample of 5 projects per state to facilitate the collection of detailed information for each project. However, we have more than 5 projects in 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.2 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 costs are higher in one state because they completed more projects than other states 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).

The 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.[116] Vehicle-miles are the estimated number of miles traveled by vehicles on roads in that state. 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 Turner et al. (2023). 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.

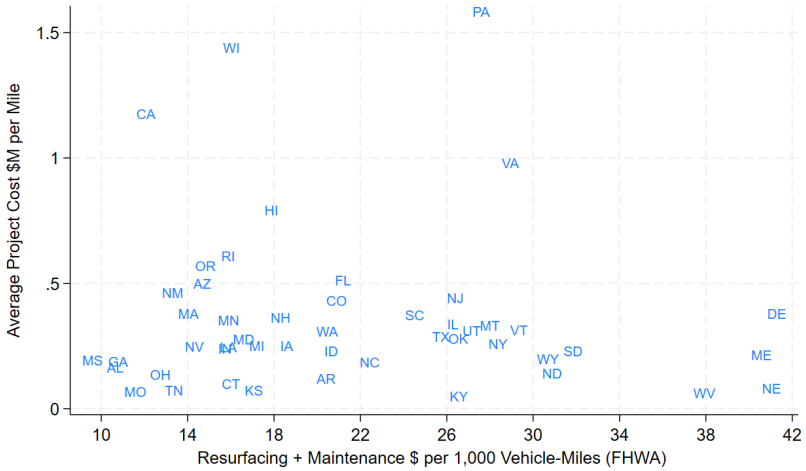
Moreover, it does not seem that costs are higher in areas where roads are rougher in the FHWA data, while our data show a stronger correlation between costs and road quality (Figure D.9). We would expect maintenance costs per lane mile to be higher on rougher, poorer-quality roads. We also compare the FHWA total spending measure to cost totals in our data for California, a state where our data covers the universe of highway construction projects.[117] Here, the total spending in the FHWA data and are own are very similar.[118] 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.

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

[117]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.

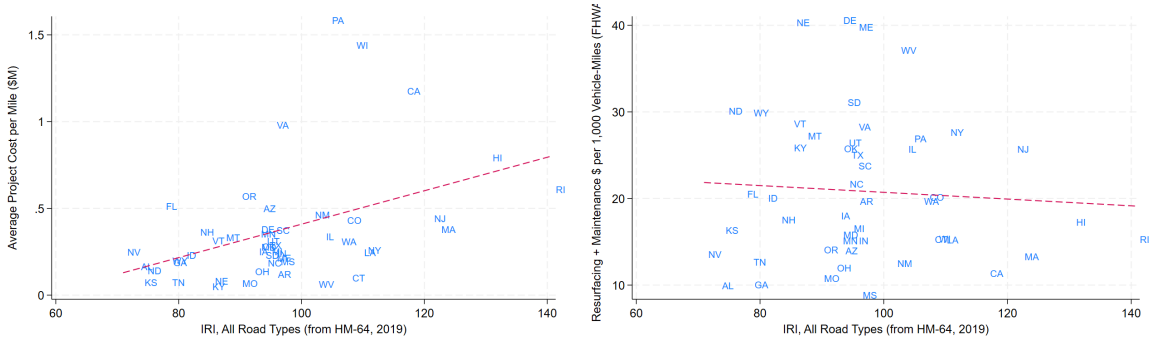
[118]Between 2015 and 2019, the total spending observed in California in our data is $28.1 billion and the total spending observed in California in the FHWA data is $24.9 billion. We believe the small difference in the total is partially due to some imprecision in how we assign project costs across years. 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.

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.2.1 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, 2023; 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.[119]

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.

[119]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 Descriptive Statistics for Table 1

Table E.1: Descriptive Statistics

	Obs.	Mean	Std. Dev.	Min.	Max.
Project Cost per Mile ($M)	250	0.37	0.51	0.01	5.19
Project log(Cost per Mile)	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 per 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	50	38.67	14.44	9.96	70.00
Winter Low	50	23.50	11.91	1.10	68.00
Snow Proxy	50	2.60	4.72	0.36	34.54
Summer High	50	83.61	6.07	60.20	94.20
Roughness Index	50	96.60	14.81	72.46	141.45
Hwy Employment per Capita (1,000)	50	0.92	0.63	0.23	3.25
State DBE Share	36	0.26	0.21	0.04	1.23
Bid Document Page Length	25	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.

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.

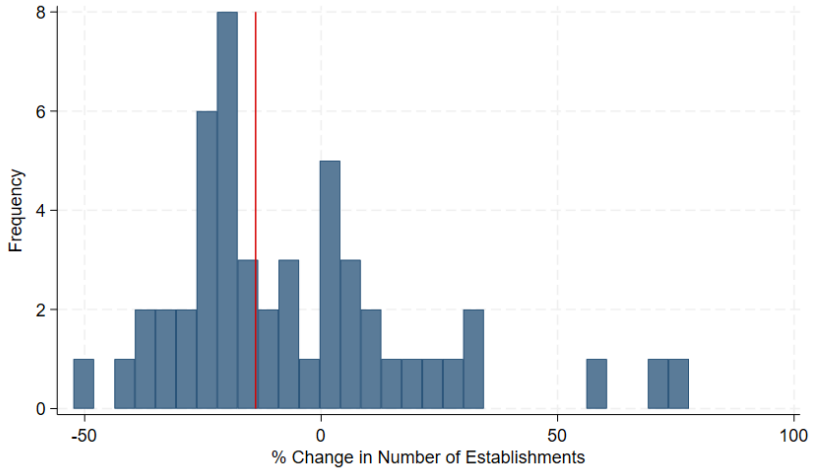
F.2 Market Structure

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 U.S. 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 population 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 the 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 J.

G Survey Details

G.1 Survey Questions

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 DOT officials and contractors 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.

G.2 Distribution

The surveys for the DOT officials and for the road builders and engineers (contractors) are slightly different. This is sometimes as simple as question phrasing, but there are also questions that are group-specific.[120] Therefore, we launch the survey separately for DOT officials and for contractors.[121] The sample and survey distribution method for each group is described below.

We collect contact emails for DOT officials from two sources: the state DOT websites and the American Association of State Highway and Transportation Officials (AASHTO), a trade association for DOT officials.[122] We directly email the survey to these contact emails. Respondents follow a link to complete the survey via Qualtrics.[123] We also collect contact emails for the contractors from trade associations and each state's public DOT website. Here we use public announcements of winning bidders or lists of pre-qualified firms.[124] As with the DOT officials, we email the contractors

[120] As an example, 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 DOT official, 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?*" We only ask the contractors about their expectations of the level of competition.

[121] In general, the DOT officials are civil engineers that are involved in the planning, procurement and delivery of highway construction projects.

[122] We use the contact lists for AASHTO's Maintenance, Construction, Design, Materials, and Planning committees.

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

[124] The contact information sometimes includes only the firm name and phone number, so we then use google to find

directly.[125]

Appendix Figure H.1 shows the geographic distribution of survey respondents. We have 123 survey responses from DOT officials in 50 states plus the District of Columbia.[126] 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.[127] The firms we survey often operate in many states, but we ask them to consider their primary state of operation 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.

the firm's email address.

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

[126]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 DOT 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.

[127]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`).

H Survey Descriptives

Figure H.1 shows the geographic distribution of survey respondents. In the remainder of this section we present additional descriptives from the survey, and a longer discussion of some of the descriptives we mention in the main text. The full survey, with responses, is available as the final Appendix Section of this paper.

We 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 (Figure H.2). Moreover, after developing the project plans and cost estimates, there is variation in how much information is shared with bidders (Figure 1(b)). Strikingly, 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.[128] 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 Figures H.3(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. The average is just under a month, and a standard deviation is 18 days. The contractors report an even higher number of days in each question.

Figure H.4 shows the responses on employee quality. About 30% of the respondents rated the quality of the employees at the DOT as "very high" and 60% at "moderately high." The private-sector contractors that work with the DOTs are in agreement, though they do not feel as positively about employee quality.

Figure H.6 tabulates the responses to our question of whether there are labor or subcontracting requirements that increase costs. DOT officials and contractors both overwhelmingly cite the Disadvantaged Business Program (DBE, a federal program) and the Minority and Women Owned Business

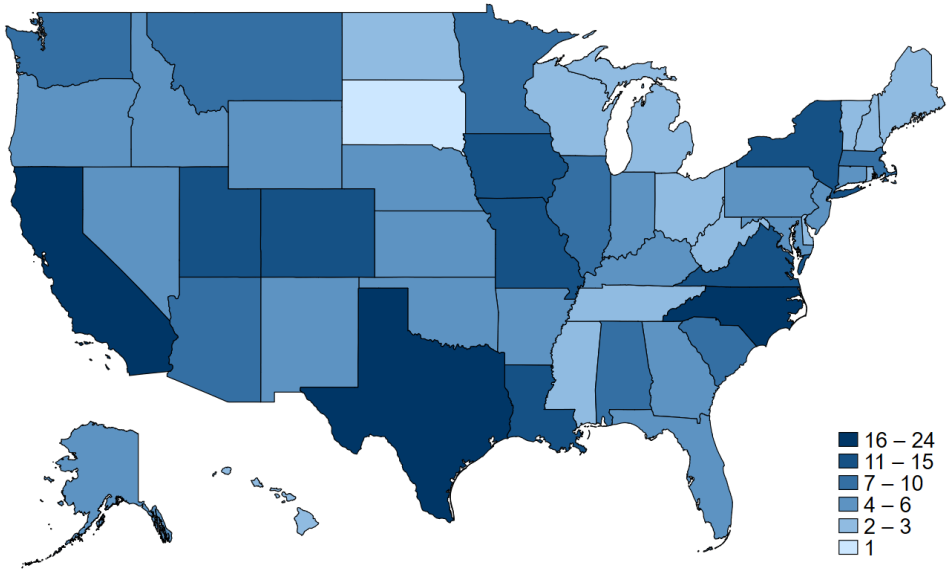
[128] We do not observe the purchasers of plans in the data so we do not know how often firms purchase the project plans and do not bid.

Program (MWBE, these are state programs) as cost drivers. The next most cited cost driver are limits on the share of work that can be subcontracted. DBE and MWBE programs are also forms of subcontracting requirements, and we investigate this further in Appendix J.

The next set of results concern competition between bidders. First, Figure H.7(a) shows that in states where contractors report facing fewer bidders, competition is more likely to be cited as a cost driver in the free response. We find that contractors who expect to face fewer bidders are more likely to know all of their competitors (Figure H.7(b)), irrespective of the information shared by the DOT. Table H.1 shows the break down of contractor responses about competition, and Figure H.8 correlates bidder outreach and number of bidders with the survey response on employee quality.

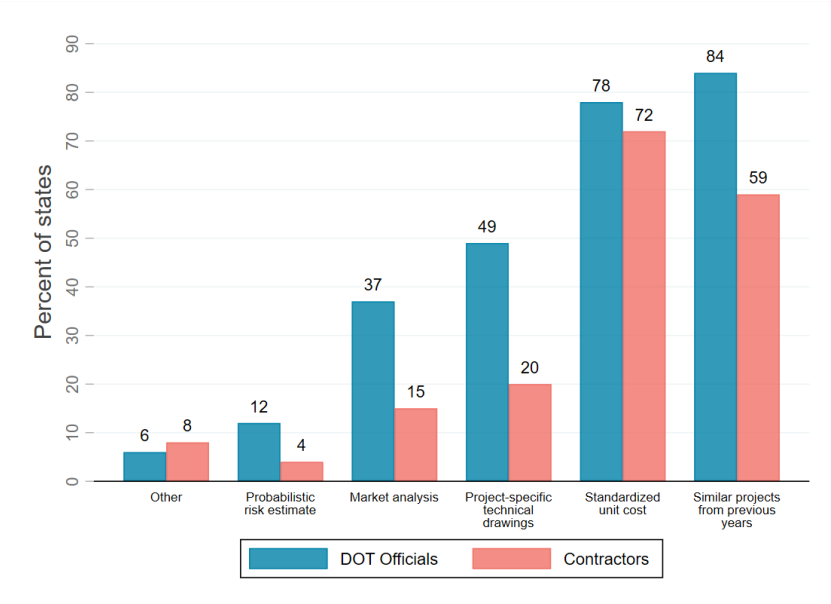
Finally, Figure H.9 shows the distribution of responses about corruption.

Figure H.1: Survey Respondents by State



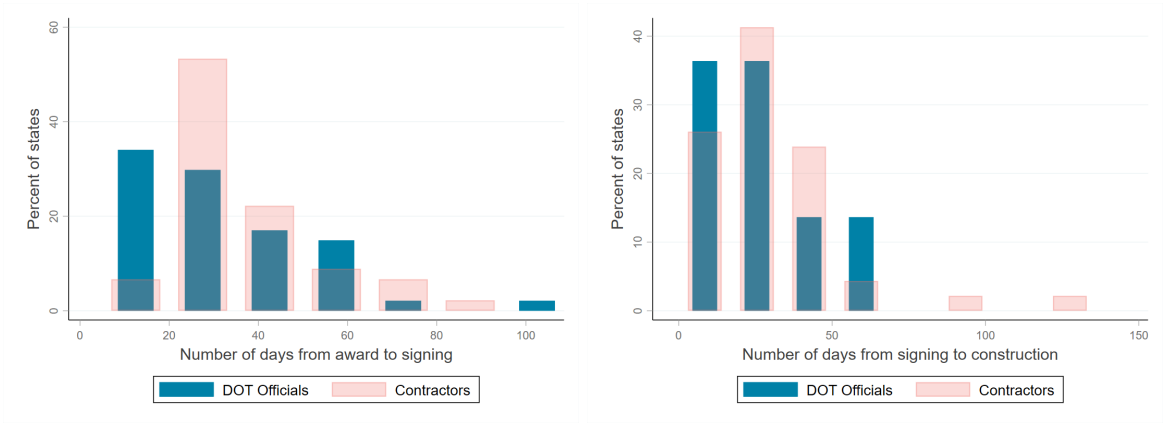
Notes: The map displays the total number of survey respondents by state. This includes both DOT officials and contractors. Contractors are classified according to their primary state.

Figure H.2: Estimating Contract Costs



Notes: Author survey. Respondents are asked "*To the best of your knowledge, when the agency prepares to advertise a new procurement opportunity for a contract like the one described in the case study, which of the following does the agency use to estimate the contract value and projected schedule? Select all that apply.*" Data collected by authors, and aggregated to the state level. Survey available in Appendix O.

Figure H.3: Variation in Timing Across States

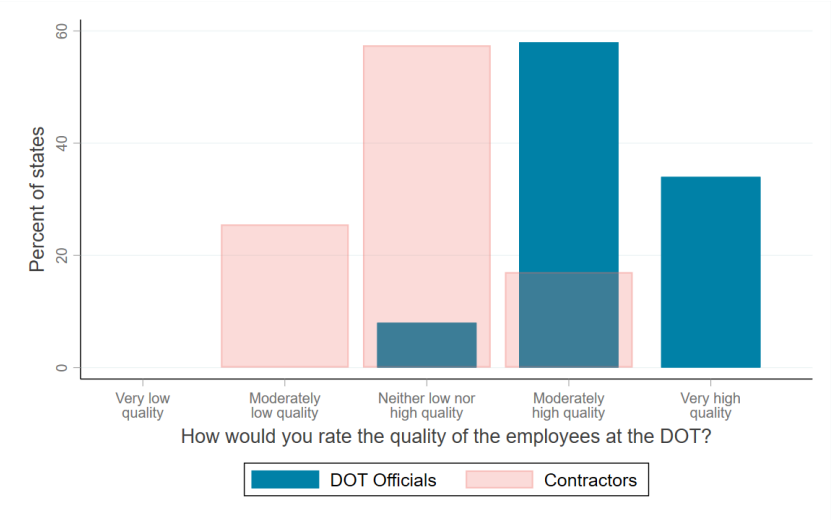


(a) Award to Signing

(b) Signing to Construction

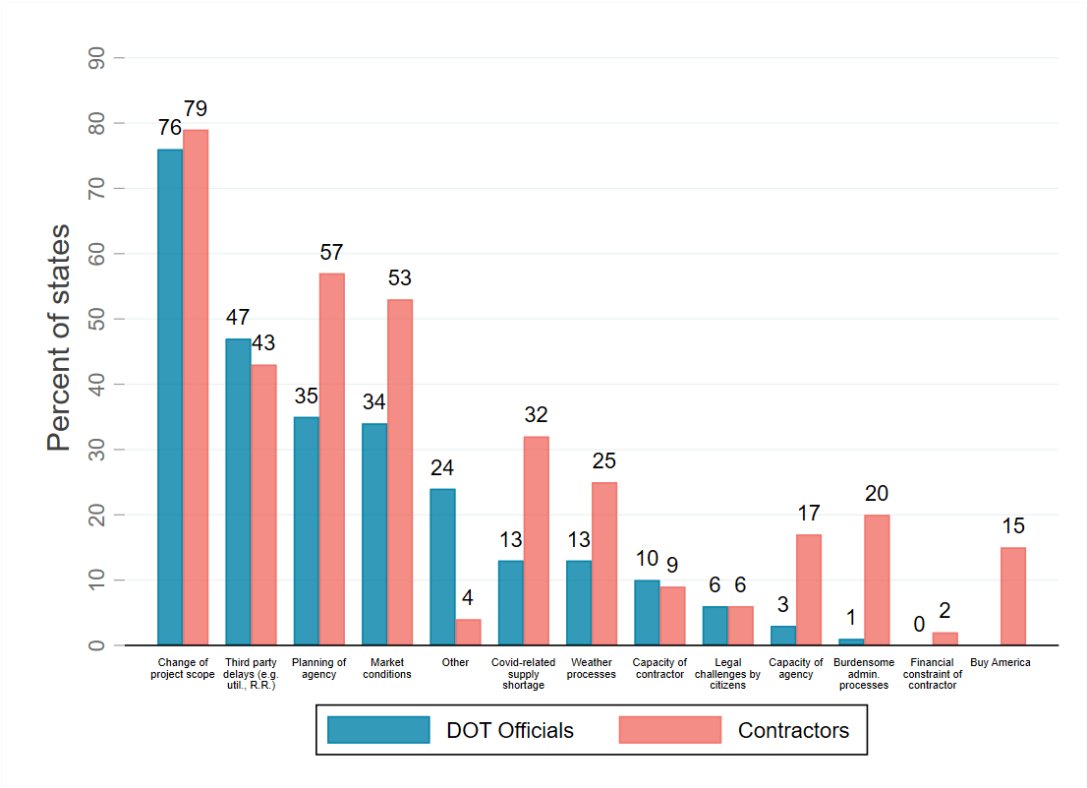
Notes: Author survey. Panels (a) and (b) ask the number of days from contract award to signing and contract signing to the start of construction. Data aggregated to the state level. Survey available in Appendix O.

Figure H.4: State DOT Employee Quality



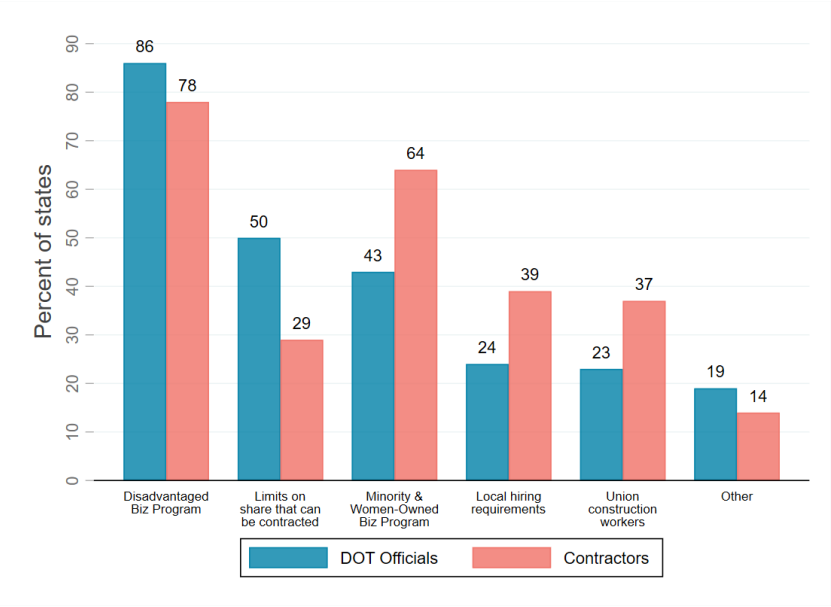
Notes: Author survey. Survey question on x-axis and frequency of response on y-axis. Data aggregated to the state level. Survey available in Appendix O.

Figure H.5: Reasons for Cost Overruns



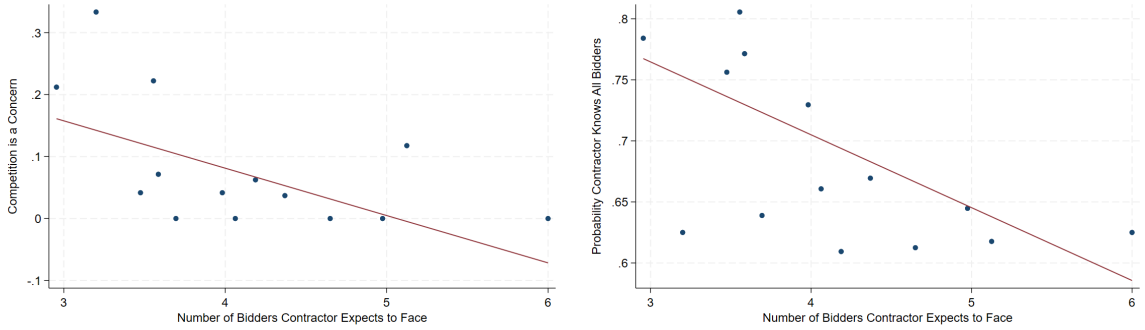
Notes: Author survey. Respondents are asked "*If a project has a cost overrun, what are usually the main reasons? Select all that apply.*" Data aggregated to the state level. Survey available in the Appendix. Only contractors were given the option to choose "Buy America."

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



Notes: Author survey. Respondents are asked "*Are there any labor and/or subcontracting requirements that increase costs?*" Data aggregated to the state level. Survey available in Appendix O.

Figure H.7: Competition

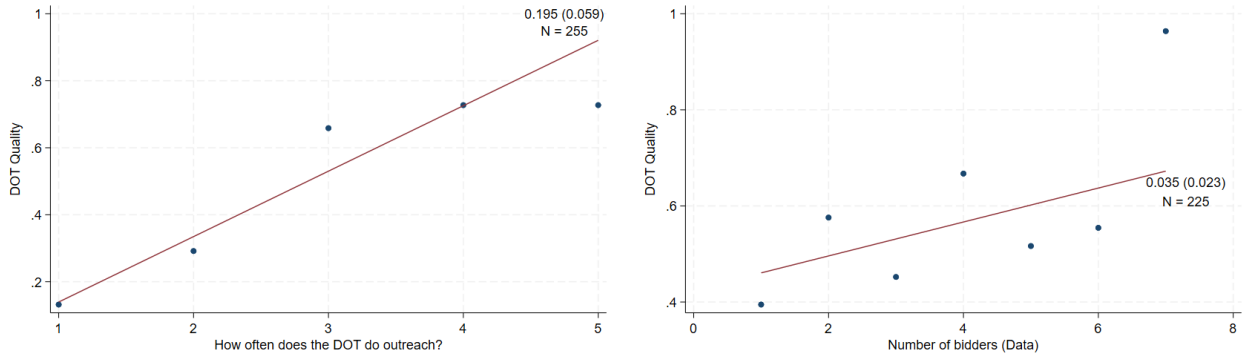


(a) Stated Concerns and # of Bidders

(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 H.8: DOT Quality and Competition



(a) DOT Quality and Outreach

(b) DOT Quality and Number of Bidders

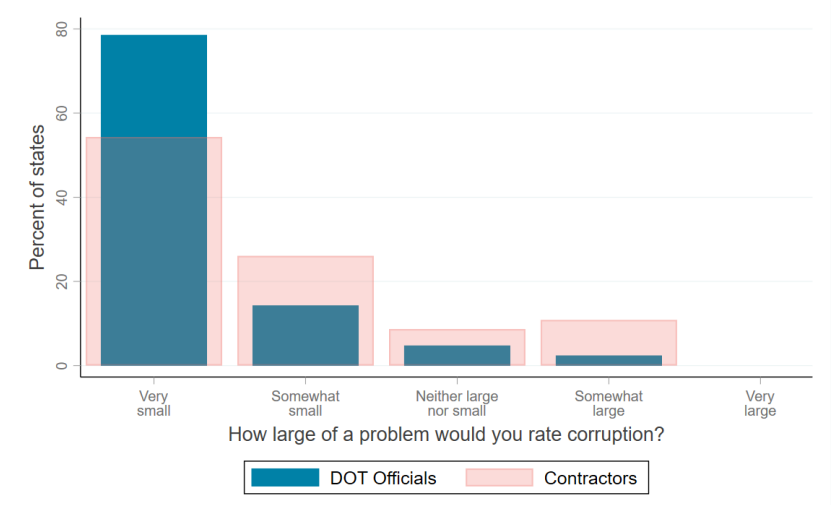
Notes: The panel on the left shows a binned scatter plot with the DOT quality on the y-axis and the frequency of DOT bidder outreach on the x-axis. This data is from the author survey, and responses are reported at the individual level. DOT quality ranges from -2 to 2, with 0 being neutral. The panel 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, observations are at the project level for the number of bidders, but the survey variable for DOT quality is aggregated to the state level.

Table H.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 H.9: Corruption



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

H.1 Free Response Questions

We begin our analysis of cost drivers with a textual analysis of responses to the survey question, "*What do you think are the main aspects of the procurement and administrative process of highway construction that increase construction costs?*" Specifically, we extract bigrams from the responses. 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."

A commonly cited cost driver that we do not discuss in the main text 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. 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 H.10: 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 O). 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 DOT officials and contractors are used.

Table H.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).

Table H.3: Key Words for 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

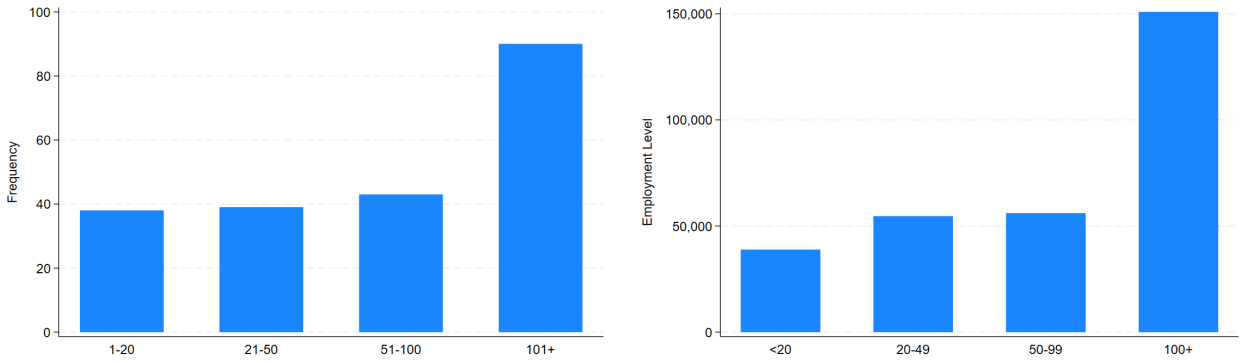
H.2 Contractor Characteristics

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 H.11).

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 DOT officials' responses about the lack of competition.

Figure H.11: 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.

H.3 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 DOT practices in State X, and we attribute those practices to State Y. Results using these additional cleaning methods are not substantially different from our main results.

I Survey Correlations: Full Results

When we developed the survey, we had five broad hypotheses on cost drivers (Appendix G). While we find evidence for the competition and capacity hypotheses, which we discuss in the main text, we find no relationship between realized costs and questions on transparency, quality, or corruption. 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.

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 (Table I.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.

Table I.1: Planning 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
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: The dependent variable is log cost per mile. Regressions include controls for project, local, and weather observables (per Column (2) of Table 1). The survey responses from the DOT 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 DOT officials only. ˆquestion asked to contractors only.

Table I.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 bidders submit unrealistically low bids to win?†	-0.02	0.87	1.00
Are you ever concerned about your bids being declared math. 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: The dependent variable is log cost per mile. Regressions include controls for project, local, and weather observables (per Column (2) of Table 1). The survey responses from the DOT 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 DOT officials only. ˆquestion asked to contractors only.

Table I.3: Cost Overruns and Delays

Variable	β	Unadjusted p-value	Romano-Wolf p-value
Main reasons for project delays:			
Selected 'Administrative processes'	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
Selected 'Subcontracting limits'	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: The dependent variable is log cost per mile. Regressions include controls for project, local, and weather observables (per Column (2) of Table 1). The survey responses from the DOT 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 DOT officials only. $\hat{}$question asked to contractors only.

Table I.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: The dependent variable is log cost per mile. Regressions include controls for project, local, and weather observables (per Column (2) of Table 1). The survey responses from the DOT 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 DOT officials only. ˆquestion asked to contractors only.

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

	Project-Level log(Cost per Mile)		
	(1)	(2)	(3)
Project Details:			
Complex Dummy	0.818***	0.757**	1.039***
	(0.282)	(0.324)	(0.285)
Mileage	-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 3
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. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15

Table I.6: What does the agency publish before bids are due?

	log(Cost per Mile)
Selected 'Estimated contract value'	0.22**
	(0.10)
Selected 'Number of bidders'	0.07
	(0.21)
Selected 'Identity of bidders'	0.07
	(0.17)
Selected 'Estimated/standard unit costs'	-0.05
	(0.16)
Selected 'Bid bond'	-0.07
	(0.16)
Selected 'Project plans'	-0.13+
	(0.09)
R-squared	0.39
Observations	250

Notes: This table shows the correlation between the responses to "*What does the agency publish before bids are due?*" and realized costs. The dependent variable is log cost per mile. The survey responses from the DOT officials and the contractors are aggregated to a state-level average. Each response variable is normalized to have a mean of zero and standard deviation of one, such that correlations are comparable across questions. This table reports unadjusted p-values, which are computed using standard errors clustered at the state level. Regressions include controls for project, local, and weather observables (per Column (2) of Table 1). ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15

J Subcontracting Requirements and Competition

DOT officials and contractors in over 80% of states mentioned the Disadvantaged Business Enterprise (DBE) program as a cost driver (Appendix Figure H.6). However, we do not find any correlation 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, one of the significant correlations that we find is the relationship between subcontracting limits and costs. Given that correlation, we use the DBE program as a case study to further probe the role of competition in the subcontracting market. In effect, the DBE program works as a limit on subcontracting—it puts restrictions on the type of firm that the prime contractor can subcontract with. Therefore, 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.

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). 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.

Table J.1 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. However, in states with thicker DBE markets costs are, weakly, lower. Of course, these are correlations, and projects with high DBE goals could differ from others 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. We view this as an additional piece of evidence for the role of competition as a cost driver.

Table J.1: Project Costs and Subcontracting Requirements

	log(Cost per Mile)	
	(1)	(2)
Project DBE Goal (%)	0.022+	0.025*
	(0.014)	(0.014)
State DBE Share		-0.254
		(0.286)
Observations	119	119
R-squared	0.49	0.49

Notes: All columns use the regression specification from Column (2) of Table 1 (project details, local characteristics, state weather). 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). Standard errors are clustered at the state level. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15

K Caltrans Background and Data

K.1 What does a Transportation Engineer do?

The majority of engineers in our data are "Transportation Engineer (Civil)." This includes 58% of retirements, 83% of Construction Heads, and 23% of Project Heads. 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 transportation 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:[129]

> "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 a Construction Head (resident engineer) or Project Head (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. As a first finding, we find that the engineers are important in explaining variation in costs—adding both sets of engineers (Construction Head and Project Head) increases the adjusted R-squared from 0.45 to 0.52. (Table K.1).

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

Table K.1: Explanatory Power of Caltrans Engineers

	Construction Head Sample				Project Head Sample				
Fixed Effects:									
Project Type × Mileage	×	×	×	×	×	×	×	×	×
District	×	×	×	×	×	×	×	×	×
Year	×	×	×	×	×	×	×	×	×
County		×	×	×		×	×	×	×
Route			×	×			×	×	×
Construction Head ID				×					×
Project Head ID								×	×
Adj. R-squared	0.40	0.40	0.42	0.46	0.43	0.43	0.45	0.49	0.52
R-squared	0.40	0.42	0.47	0.58	0.44	0.46	0.52	0.64	0.77
Observations	3,664	3,660	3,633	3,442	1,819	1,815	1,775	1,695	1,499
Residual Sum of Squares	8,314.14	8,146.21	7,353.24	5,349.84	4,219.35	4,080.06	3,589.94	2,570.77	1,345.31

Notes: The table presents the R-squared and residual sum of squares for a regression of log cost per mile on a set of fixed effects. This is performed on two samples: the "Construction Head Sample," all projects where we can observe the identity of the Construction Head, and the "Project Head Sample," all projects where we can observe the identity of the Project Head (this is a subset of the Construction Head Sample).

K.2 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 (Construction Heads, in our parlance):[130]

> "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."

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 Head, before moving to upper management. He described the assignment of Project Heads to projects as follows: "*Managers*

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

do not want to assign inexperienced PMs [Project Heads] 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 assigned by county), 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* the assignment mechanism.

K.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 use 6 verb categories: build, install, planting/irrigation, rehabilitation, resurfacing, widen. Table K.2 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 K.3 shows the distribution of cost per mile for the types, and the number of observations, for the sample of projects we use in the analysis.

Table K.2: 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 K.3: Cost per Mile ($M) by Project Type

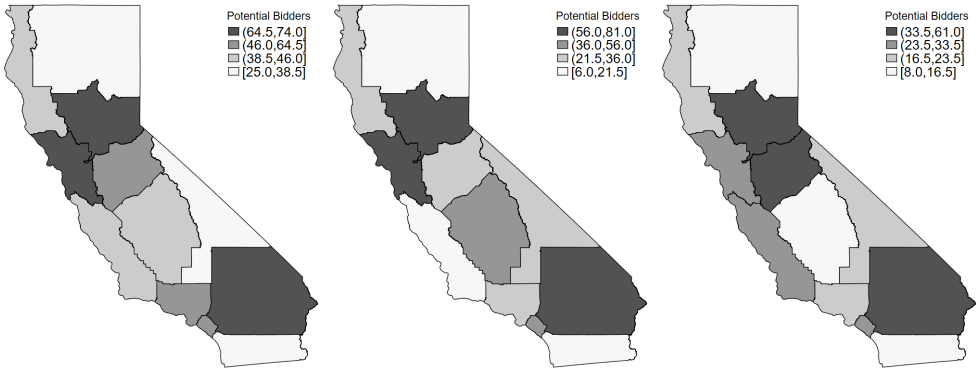
Project Type	Mean	Median	SD	N
build:bridge	19.0	7.4	28.6	15
build:other	20.0	0.9	73.8	75
build:road	25.3	6.2	94.6	52
build:road, aux.	10.1	1.3	35.1	171
install:other	1.5	0.2	3.5	104
install:road, aux.	1.5	0.4	4.7	131
planting/irrigation: other	2.1	0.5	5.5	247
rehabilitation:bridge	6.5	1.0	16.0	171
rehabilitation:other	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 engineer quality analysis.

K.4 Competition across Caltrans Markets

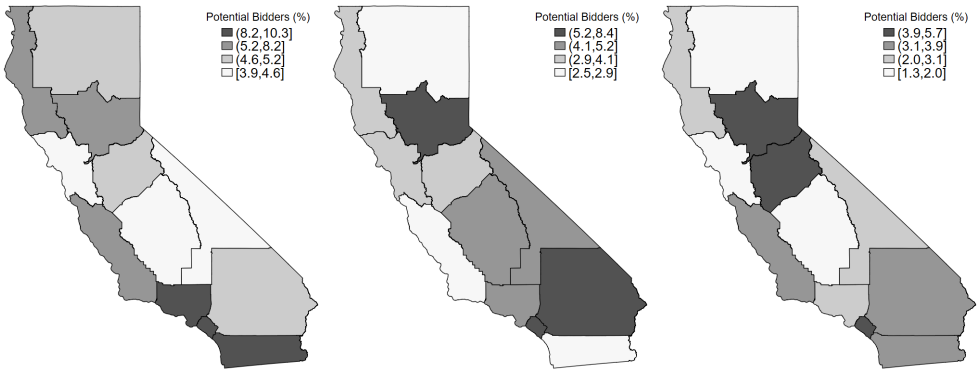
We measure the competition in a Caltrans market using data on the identity of bidders on each project from 2018-2023. Figure K.1 shows the variation in competition across markets. Our first measure of competition is the number of potential bidders in each "market," which we define as a project type-district pair. For example, the market for road resurfacing projects in District 1 would consist of the set of firms that ever bid on a road resurfacing project in District 1. Of course, some of the variation in the number of potential bidders reflects smaller markets and less demand from the district. As a second definition, we control for the size of the district—the number of potential bidders is divided by the total number of projects completed by the district.

Figure K.1: Varying Levels of Potential Bidders in Caltrans Auctions



(a) Road Resurfacing (b) Road Rehabilitation (c) Road Widening

I. Potential Bidders



(d) Road Resurfacing (e) Road Rehabilitation (f) Road Widening

II. Potential Bidders by District Size

Notes: This figure shows the variation in potential bidders across markets. A market is defined as a project type-district pair. California is divided into 12 districts, as shown in the maps. Each map represents a different project type: (a) Road Resurfacing, (b) Road Rehabilitation, and (c) Road Widening. The darker shading represents more competition, i.e., more potential bidders.

L Measuring Engineer "Quality"

We collect the salary and job title for each engineer (Construction Head and Project Head) 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."[131] We create a compensation measure that is the sum of "Regular Pay" and "Benefits." We inflation adjust this measure to 2018 dollars.

Table L.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 Construction Heads in our data (% CH in the table). Project Heads (% PH) are more likely to be senior transportation engineers, but still 23% are staff transportation engineers. Table L.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."

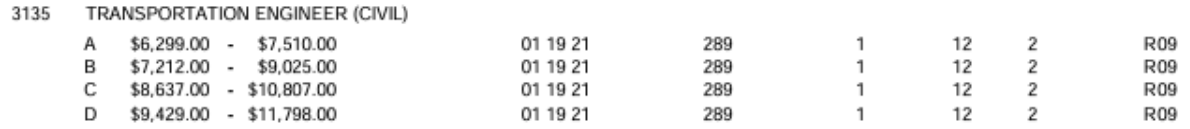
Table L.1: Compensation and Project Position by Job Title

	Salary and Benefits ($2018)				Percent of (%)		
Job Title	Mean	Median	SD	N	Total	CH	PH
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 Construction Heads (CH) and Project Heads (PH) that have each job title.

[131] There are very few records with a non-zero value in "Other Pay."

Figure L.1: 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 L.1 shows a screenshot of the pay scale for staff transportation engineers (associate, senior, etc. have a separate pay scale) (CalHR, 2025). 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 from Caltrans 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. Salary progresses as a function of both of these underlying variables, which we do not observe independently. Table L.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 L.2 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 (i.e., Construction Head vs Project Head). If senior engineers are more likely to be in the Project Head position, the relevant experience is their experience as a Project Head, dealing with multiple phases and communicating with multiple stakeholders—not just their time as a staff

Table L.2: Compensation Regressions

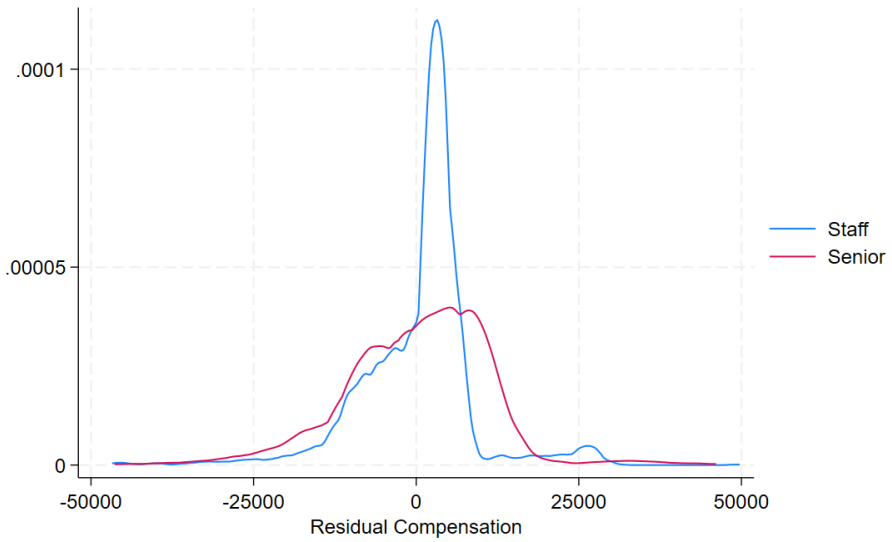
	Compensation = Salary + Benefits ($2018)			
	(1)	(2)	(3)	(4)
Year (Base is 2011)				
2012	2,499.82***	2,382.23***	3,632.40***	2,580.73***
	(793.16)	(638.47)	(919.91)	(644.24)
2013	-6,385.71	-1,899.94	12,415.03	5,891.97
	(7,179.47)	(7,592.93)	(15,257.86)	(8,027.01)
2014	-1,176.36	4,452.76	19,007.96	12,294.21+
	(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. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15

engineer drawing up plans or in the construction team.

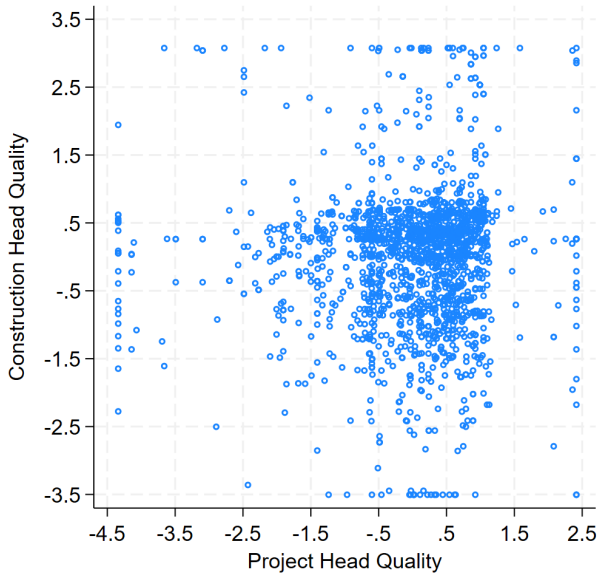
In Table 3, we use the residual to predict the number of years of experience of our Construction Heads. Here, we take engineer years on the job from the construction data, where we see Construction Head assignment from 1970-2023, and therefore use the first year we see an employee as a Construction Head as their starting year. This is not a perfect measure. First, it 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 Construction Heads 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 Construction Head task. Given those caveats, Table 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 Construction Head. However the R-squared is relatively low. Measurement error in the years of experience variable 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 L.2: Residual Compensation for the Full Sample



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

Figure L.3: Quality Pairs for each Project

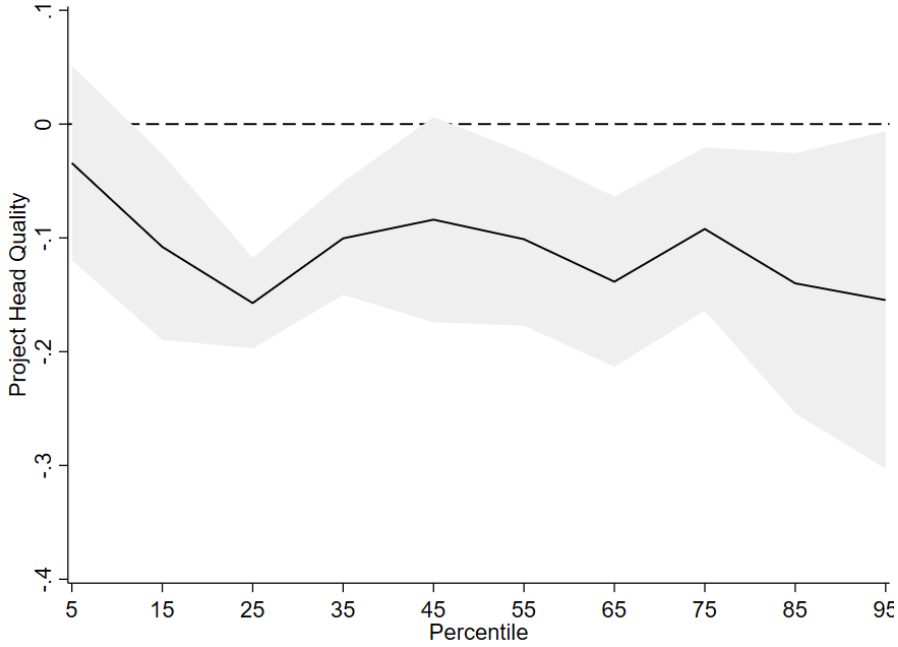


Notes: This figure shows the residual quality for the Construction Head and Project Head pairs that are assigned to the same projects. The residual quality are winsored at the 1% level and standardized.

L.1 Additional Quality Results

Table L.3 shows the results of engineer quality on cost overrun and duration. Cost overrun excludes emergency projects and projects with winning bids less than $5,000. Duration is measured in days per mile. We find no effect of quality on duration, and a small negative effect on overrun.[132] Figure L.4 shows the relationship between Project Head quality and log cost per mile, throughout the cost distribution. The figure shows the coefficient on Project Head quality from a quantile regression, where the x-axis plots the corresponding quantile. The regression specification is the same as Table 4, Column (5). Table L.4 replicates our results in the main text (Table 4), but using wild cluster bootstrapped confidence intervals, which allows us to cluster at the district level. Table L.5 reports the baseline results in levels, instead of log cost per mile.

Figure L.4: Quantile Effects



Notes: The table presents the results of estimating Equation 1, with district and year fixed effects and project characteristics: mileage, project-type dummies, mileage × project type interactions, a zero mileage dummy, and an indicator for the seniority of the Construction Head. The baseline (OLS) result is -0.11, which is reported in Table 4, Column (5). This figure shows the quantile results, where the x-axis plots the quantile at which the equation is estimated.

[132]When we include emergency projects, quality of the Construction Head is important in reducing overrun, but overrun is not a well-defined concept in these cases, because most projects do not go through a competitive bidding process.

Table L.3: Engineer Quality, Cost Overruns, and Duration

	Cost Overrun (%)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Construction Head Quality	-0.32		-0.31	-0.04		-0.01	-0.87*		-0.82*
	(0.38)		(0.38)	(0.45)		(0.46)	(0.46)		(0.46)
Project Head Quality		-0.27	-0.26		-0.51	-0.51		-0.77+	-0.73+
		(0.43)	(0.43)		(0.49)	(0.50)		(0.48)	(0.48)
$\text{Quality}_{\text{CH}} \times \text{Quality}_{\text{PH}}$			-0.08			-0.13			-0.11
			(0.35)			(0.41)			(0.37)
Adj. R-squared	0.03	0.03	0.03	0.05	0.05	0.05	0.10	0.10	0.10
Observations	1,685	1,685	1,685	1,469	1,469	1,469	1,429	1,429	1,429
	Duration (Days per Mile)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Construction Head Quality	-19.85		-18.59	1.86		2.85	-16.71		-15.74
	(18.28)		(18.25)	(16.95)		(16.93)	(20.14)		(20.10)
Project Head Quality		-22.26	-21.12		-20.77	-20.71		-22.61	-22.01
		(21.43)	(21.44)		(19.46)	(19.49)		(21.63)	(21.60)
$\text{Quality}_{\text{CH}} \times \text{Quality}_{\text{PH}}$			-16.81			-8.97			-5.23
			(14.87)			(14.06)			(15.14)
Adj. R-squared	0.03	0.03	0.03	0.21	0.21	0.21	0.24	0.24	0.24
Observations	1,481	1,481	1,481	1,481	1,481	1,481	1,442	1,442	1,442
District, Year FE	×	×	×	×	×	×	×	×	×
Project Characteristics				×	×	×	×	×	×
County, Route FE							×	×	×

Notes: The table presents the results of estimating Equation 1. Columns (1) - (3) only include district and year fixed effects. Columns (4)-(6) add project characteristics: mileage, project-type dummies, mileage × project type interactions, a zero mileage dummy, and an indicator for the seniority of the Construction Head. Columns (7) - (9) add the county and route fixed effects. The outcome and quality variables are winsorized at the 1% level. Cost overrun excludes emergency projects and projects with bids under $5,000. Slight differences in availability of cost, mileage, and duration outcomes explain differences in the number of observations between the outcome variables. Quality for both the Construction Head (CH) and Project Head (PH) are standardized to have mean zero and unit variance. Robust standard errors reported in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1, +p < 0.15

Table L.4: Engineer Quality and Project-Level Cost with Wild Bootstrap Clustering

	log(Cost per Mile)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\text{Quality}_{\text{CH}}$	-0.05		-0.04	0.03		0.03	-0.01		-0.01
	[-0.14,0.04]		[-0.13,0.05]	[-0.05,0.11]		[-0.05,0.12]	[-0.09,0.07]		[-0.09,0.08]
$\text{Quality}_{\text{PH}}$		-0.11*	-0.11*		-0.11*	-0.11*		-0.11*	-0.11*
		[-0.23,0.01]	[-0.23,0.01]		[-0.23,0.02]	[-0.22,0.01]		[-0.23,0.01]	[-0.22,0.00]
$\text{Quality}_{\text{CH}} \times \text{Quality}_{\text{PH}}$			-0.04			-0.05			-0.05
			[-0.16,0.08]			[-0.14,0.04]			[-0.14,0.04]
Adj. R-squared	0.03	0.04	0.04	0.44	0.45	0.45	0.46	0.46	0.46
Observations	1,733	1,733	1,733	1,733	1,733	1,733	1,687	1,687	1,687
District, Year FE	×	×	×	×	×	×	×	×	×
Project Characteristics				×	×	×	×	×	×
County, Route FE							×	×	×

Notes: The table presents the results of estimating Equation 1. Columns (1) - (3) only include district and year fixed effects. Columns (4)-(6) add project characteristics: mileage, project-type dummies, mileage × project type interactions, a zero mileage dummy, and an indicator for the seniority of the Construction Head. Columns (7) - (9) add the county and route fixed effects. Quality for both the Construction Head (CH) and Project Head (PH) are standardized to have mean zero and unit variance. Confidence intervals are calculated using the wild cluster bootstrap method, with district-level clustering. ***p < 0.01, **p < 0.05, *p < 0.1, +p < 0.15

Table L.5: Engineer Quality and Project-Level Costs, in Levels

	log(Cost per Mile)		Cost per Mile ($)			
	(1)	(2)	(3)	(4)	(5)	(6)
Project Head Resid. (Normalized)	-0.11**	-0.11**	-484,300.48*	-480,466.09*		
	(0.04)	(0.04)	(256,328.19)	(255,434.58)		
Project Head Resid. ($)					-38.40*	-37.75*
					(20.33)	(20.27)
Project Characteristics	×	×	×	×	×	×
District, Year, County, Route FE	×	×	×	×	×	×
Construction Head Interaction		×		×		×
Adj. R-squared	0.46	0.46	0.22	0.22	0.22	0.22
Observations	1,687	1,687	1,687	1,687	1,687	1,687

Notes: The table presents the results of estimating Equation 1. Columns (1) and (2) replicate Columns (8) and (9) from Table 4, to establish the baseline specification, which includes project characteristics as well as district, year, county, and route fixed effects. Robust standard errors reported in parentheses. Columns (3) and (4) replace the log(Cost per Mile) outcome variable with Cost per Mile in levels ($). Columns (5) and (6) replace the normalized Project Head Residual measure with the measure in levels ($). Therefore, Columns (5) and (6) show that a $1 increase in residual compensation to the engineer is associated with about a $38 decrease in cost per mile. ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1, +p $<$ 0.15

M Caltrans 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.[133] 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." This covers the vast majority of engineers in our sample of Project Heads and Construction Heads, and we know from the institutional details that this is the majority of engineers at Caltrans. Appendix Table M.1 shows the distribution of retirements, by title. The staff engineers (Transportation Engineer (Civil)) retire with 26 years of experience, on average.[134] Then, there are senior engineers (associate, senior, principal, and supervising transportation engineers) who have slightly more experience at retirement (31 years, on average).

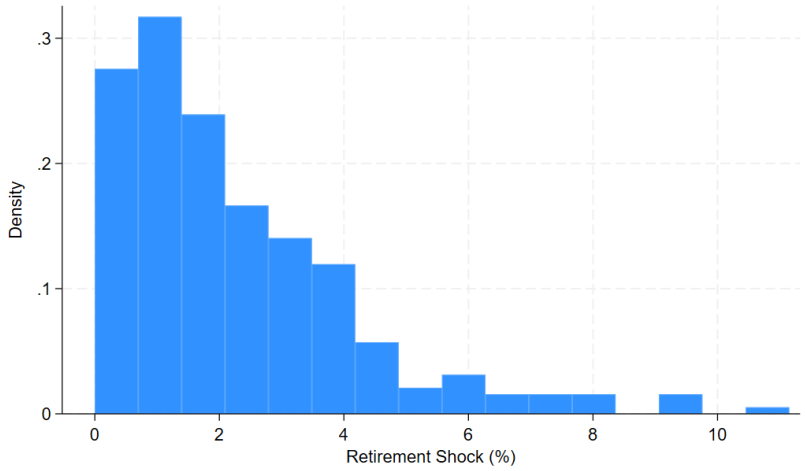
We also have the universe of project-level cost data from the Caltrans construction division, as we describe in the main text. We exclude some projects that do not follow typical construction or maintenance timelines, such as planting and irrigation contracts that have a fixed duration. Otherwise, we 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 Covid-19 pandemic on our results. Our final sample has 9,600 projects over 12 districts and 19 years.

We describe the construction of our retirement shock in the main text, but we show the distribution in Figure M.1. Figure M.2 complements Table M.1 by showing the full distribution of years of service at retirement. Then, we show some time series trends with Figure M.3. Figure M.3(a) shows that the years of service at retirement has decreased over the last 30 years—from an average of about 35 in the 1990s, to an average of about 27 since 2010. At the same time, the number of retirements by year has increased, with some notable spikes in 2000, 2017, and 2020 (Figure M.3(b)). The spike in 2000 is likely due to S.B. 400, a state law that lowered the full benefit pension-eligible age from 60 to 55.

[133] 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.

[134] Employees need to be 50 and have worked with Caltrans for 5 years to receive a pension. Generosity of benefits can also vary with age at retirement.

Figure M.1: Distribution of Retirement Shocks



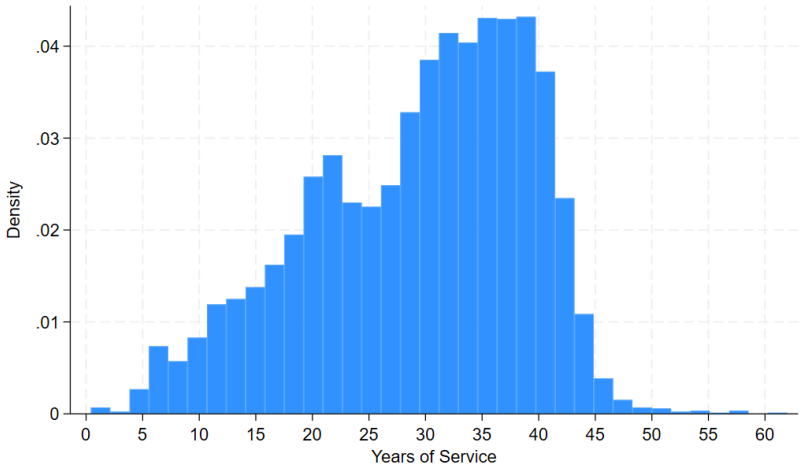
Notes: This figure shows the distribution of retirement shocks in the data. Retirement records are from "Transparent California." This figure uses any retirement of any engineer whose final job title was "Transportation Engineer." The denominator for the shock is the number of engineers we estimate in 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 M.1: 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

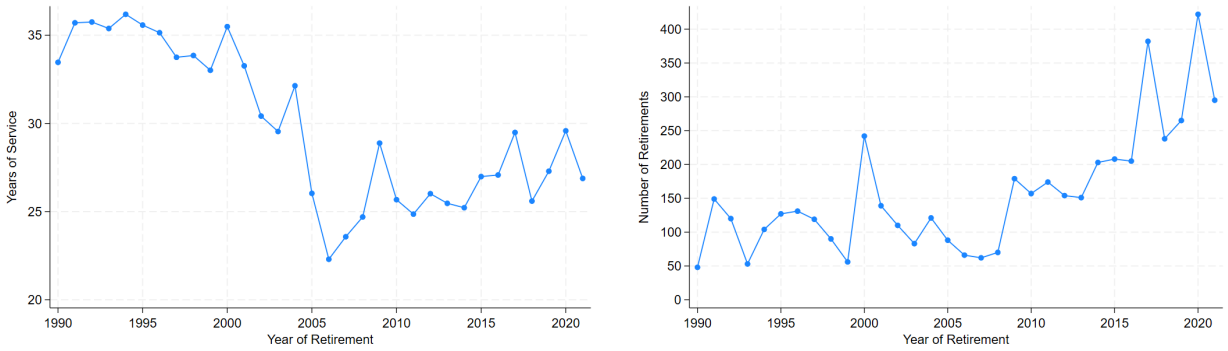
Notes: Table M.1 shows the distribution of retirements in the data, by job title. Retirement records are from "Transparent California." We study retirements between 2000-2018.

Figure M.2: Years of Service at Retirement



Notes: This figure shows the distribution of years of service at retirement in our sample of Caltrans engineers. Retirement records are from "Transparent California." This is a sample of employees who retire with a pension. To qualify, the employee needs at least 5 years of service, and must be at least 50 years old at retirement.

Figure M.3: Retirement Statistics by Retirement Year



(a) Years of Service at Retirement

(b) Number of Retirements

Notes: The figure on the right shows the average years of service of employees at the time of retirement, by their retirement year. The figure on the right shows the total number of engineers retiring from a Caltrans District or HQ, by year. Retirement records are from "Transparent California."

M.1 Additional Retirement Results

Table M.2 studies the effect of retirements on the *composition* of a District's projects. This is measured by the number of projects, the scope (mileage), and the share of project types. See Appendix Section K.3 for more on how we classify type of work. Table M.2 shows that the Districts do not award more or larger projects in years with larger retirement shocks. The only project type of work that marginally increases (1 percentage point, or 3%), is rehabilitation projects—not building or widening work, which are normally the most complicated and expensive (Table K.3).

Table M.3 replicates our results in the main text (Table 6), but using wild cluster bootstrapped confidence intervals, which allows us to cluster at the district level.

Table M.2: Engineer Retirements and Project Composition

	Number of	Mileage		Share of Total Work (%)				
	Projects	Mean	Median	Build	Widen	Resurface	Rehab	Install
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	0.005	-0.105	-0.237	-0.841+	-0.122	0.321	1.016*	-0.587
	(1.012)	(0.313)	(0.234)	(0.525)	(0.370)	(0.686)	(0.532)	(0.445)
R-squared	0.81	0.31	0.33	0.29	0.30	0.54	0.60	0.26
Observations	228	228	228	228	228	228	228	228
District, Year FE	×	×	×	×	×	×	×	×
Dep. Var. Mean	48.76	9.31	4.83	11.29	8.16	29.07	31.82	12.67

Notes: The table presents regressions of the district-level retirement shock on district-level outcomes, as specified in equation 2. This is a robustness check, to verify whether retirement shocks coincide with change in the *composition* of projects a district undertakes. The outcome variables are: number of projects awarded, mean project mileage, median project mileage, and then a set of outcomes that measure the percent of each type of work. For example, the "Share Resurface" outcome is the share of total work awarded that year that is dedicated to resurfacing. Share is measured as % of total cost. All regressions include District and Year FE. The independent variable of interest, $\frac{\text{Retirements}}{\text{Engineers}}$, is measured as a percentage. Robust standard errors reported in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1, +p < 0.15.

Table M.3: Engineer Retirements with Wild Bootstrap Clustering

	log(Total Cost ($))		Cost Overrun (%)		Duration (Days)	
	Mean	Median	Mean	Median	Mean	Median
			All Engineers			
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	0.043	0.032	0.237	0.279**	10.569**	8.076+
	[-0.019,0.104]	[-0.030,0.094]	[-0.229,0.703]	[0.040,0.518]	[1.558,19.580]	[-3.327,19.480]
R-squared	0.73	0.71	0.60	0.60	0.69	0.67
			Staff Engineers			
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	0.043**	0.023	0.380*	0.351**	11.735**	7.564+
	[0.001,0.085]	[-0.012,0.058]	[-0.082,0.842]	[0.014,0.688]	[3.356,20.114]	[-2.313,17.441]
R-squared	0.73	0.71	0.60	0.61	0.70	0.66
			Senior Engineers			
$\frac{\text{Retirements}}{\text{Engineers}}$ (%)	0.016	0.019	-0.065	0.007	2.117	2.079
	[-0.019,0.051]	[-0.021,0.060]	[-0.255,0.126]	[-0.070,0.084]	[-1.972,6.207]	[-1.952,6.111]
R-squared	0.73	0.71	0.60	0.59	0.69	0.66
Observations	228	228	228	228	228	228
District, Year FE	×	×	×	×	×	×
Dep. Var. Mean	13.97	13.80	6.80	4.90	365.53	285.54

Notes: The table presents regressions 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. ***p < 0.01, **p < 0.05, *p < 0.1, +p < 0.15.

N Institutional Details on DOT Capacity

Departments of Transportation, at both the federal and state level, are concerned about an increased reliance on consultants, or outsourcing, to complete state DOT work. In 2000, the FHWA surveyed state DOTs on the level of outsourcing by work type. They found that the majority of states rely on consultants for design work, with Nevada contracting out almost all of its design. In 2006, the GAO followed up with a similar survey, which asked states about *changes* in outsourcing over the previous 5 years. They found an increase in consulting work over multiple domains; more than half the states increased the amount of engineering, design, right-of-way, and construction inspection work contracted out to consultants. Very few states reported decreasing their use of consultants; rather, the remainder maintained the same level as in the past (GAO, 2008).

The primary reason for outsourcing, as reported by the states, is "lack of in-house staff" (GAO, 2008). The GAO report documents a shortage of skilled staff across DOTs, due to retirement and turnover. Only 12 states said they had increased their employment of professional and technical staff in the last 5 years. The remaining 38 had stayed the same or declined, despite substantial increases in funding for highway programs. This is consistent with the decrease in state highway employment that we document in Figure 2.

The exact reason for the lack of in-house staff can vary by state, but is summarized here:"*Hiring and wage freezes have affected employee morale and hurt recruiting. Moreover, it is very common for in-house engineers to join consultant organizations after gaining their professional license through DOT training*" (GAO, 2008; TxDOT, 2010).[135] The report from the Texas DOT highlights the second concern: a high turnover of young engineers ("*Districts say that TxDOT is a training ground for future consultants. Until state worker compensation becomes comparable to that in the private sector, TxDOT will continue to lose trained staff*"). These employees see higher wages in the private sector and cite pay as the reason for leaving TXDOT (TxDOT, 2010).[136] We also heard this in conversation with DOT officials—engineers can be trained by the DOT and then leave for the private sector.[137]

In California, the median pay for civil engineers working in the state government is comparable to those in the private sector (CalHR, 2023). Therefore, Caltrans may not face as much of an issue

[135]More on hiring freezes from TxDOT (2010): "*Hiring freezes: Perennial hiring freezes limit the department's ability to hire and retain qualified people. Some district managers foresee a situation like in Florida DOT, where consultants manage consultants, because TxDOT would lack the experience to do PE work and to oversee it.*"

[136]The GAO (2008) report also discusses competing with private firms for a small number of new engineers graduating college each year. Some states do not offer high enough salaries to compete with the private sector from the start—this is also mentioned in our survey.

[137]Plotch (2025) highlights similar issues of attracting and retaining skilled engineers at local transit authorities.

with having their engineers leave for the private sector just after they have been trained. However, retirements remain a concern, especially given that engineers can retire with a pension at the age of 50. At the top of the distribution, wages in the private sector are higher; discussions with DOT officials and conversations on online message boards suggest that senior engineers can often make an annual salary that is at least $100,000 more in the private sector after retiring from the DOT.[138]

Across states, GAO (2008) documents that DOTs are not able to hire sufficient staff to replace the experienced employees who are retiring. In Texas, the DOT commissioned a study on their workforce shortage. They found that they were facing a substantial loss of institutional knowledge due to retirements (Deloitte, 2007), forecasting a loss of up to 70% of managers and 30% of all employees.[139]

The GAO (2008) report ends on a sobering note. State DOTs report concerns of a "thinning" of expertise, which results in not only a reliance on consultants, but fewer capable and experienced staff to actually oversee and monitor the consultants. The erosion of in-house expertise creates challenges for the state DOTs to effectively monitor both consultant and contractor work. Some DOTs—for example, Florida—already have consultants managing consultants (TxDOT, 2010). Without experienced in-house staff, it is nearly impossible to train a new generation of experienced engineers. In short, "*there is a concern among states regarding core competencies because too much outsourcing could lead to an irreversible decline in the project delivery skill sets of in-house staff*" (TxDOT, 2010).

N.1 Civil Engineer Pay in the Private and Public Sector

Figure N.1 shows the distribution of annual income for civil engineers in the public (state government) and private sectors, across the United States (Panel (a)) and then only in California (Panel (b)). We test for significant differences in the variance of the two distributions (public and private sector wages), after controlling for year, state, age, and educational attainment. The difference in variance is statistically significant at the 0.01 level for the full sample, and at the 0.05 level for the California subsample.

[138] See, for example, `https://www.reddit.com/r/CAStateWorkers/comments/14z415w/how_easy_to_max_out_salary_bu9/`.

[139] "*The department could lose a significant portion of its institutional knowledge in a few years when about 70% of managers and about 27% of all current employees will be eligible for retirement. Limited department career paths due to a mandated 11:1 supervisor/employee ratio, and an expanding private market with higher salaries, are also factors in workforce loss*" (Deloitte, 2007).

Figure N.1: Wage Distribution for Civil Engineers



(a) Full Sample



(b) California

Notes: The figures show the distribution of annual wage and salary income for civil engineers in the public sector (state government) vs. private sector, for the United States (a) and California (b). Data are from the Current Population Survey (CPS), for the years 2003-2024. Income is inflation adjusted and standardized to 2024 dollars. The figures are truncated at $500,000, but this only affects 0.6% of observations, out of a sample of 3,989.

O Survey

The survey, with tabulated responses to each question, is attached following this page. The tabulated responses are reported separately for the contractors (denoted [C]) and the DOT officials (denoted [P], for procurement). These indicators are also used to flag questions or instructions that are only asked to contractors or only asked to DOT officials. The survey can also be found online: `https://cailinslattery.com/s/Survey-with-Responses.pdf`.