# PROCUREMENT CONTRACTING WITH TIME INCENTIVES: THEORY AND EVIDENCE*

GREGORY LEWIS AND PATRICK BAJARI

In public procurement, social welfare often depends on how quickly the good is delivered. A leading example is highway construction, where slow completion inflicts a negative externality on commuters. In response, highway departments award some contracts using scoring auctions, which give contractors explicit incentives for accelerated delivery. We characterize efficient design of these mechanisms. We then gather an extensive data set of highway projects awarded by the California Department of Transportation between 2003 and 2008. By comparing otherwise similar contracts, we show that where the scoring design was used, contracts were completed 30–40% faster and the welfare gains to commuters exceeded the increase in procurement costs. Using a structural model that endogenizes participation and bidding, we estimate that the counterfactual welfare gain from switching all contracts from the standard design to the efficient A+B design is nearly 22% of the total contract value ($1.14 billion). *JEL* Codes: D44, H41, H57, L91.

## I. INTRODUCTION

Public sector procurement typically accounts for 10–15 percent of GDP in developed countries.[1] Designing efficient procurement mechanisms is therefore essential for the efficient allocation of many goods and services. Delivery time is often an important dimension of quality. In the United States however, procurement contracts are typically awarded to the lowest qualified bidder who can meet a prespecified delivery date. This does not allow for competition over completion time or other dimensions of quality. It follows that it may be possible to increase social welfare by using an alternative procurement mechanism.

*We are grateful to Saeid Asgari, Bassem Barsoum, Matthew Cugini, Perry Mayer, Mark Samuelson, Raymond Tritt, and Steven Whipple of Caltrans; Rabinder Bains, Tom Ravn, and Gus Wagner of Mn/DOT and David Kent of NYSDOT for their help. We would also like to thank John Asker, Susan Athey, Raj Chetty, Matt Gentzkow, Ken Hendricks, Jon Levin, Justin Marion, Ariel Pakes, Chad Syverson, and participants at Harvard, LSE, MIT, Toronto, UC Davis, and Wisconsin and the AEA, CAPCP, IIOC, Stony Brook, UBC IO, WBEC, and the NBER IO/Market Design/PE conferences. The editor (Larry Katz) and four anonymous referees provided extremely useful feedback. Lou Argentieri, Jorge Alvarez, Minjung Kim, Jason Kriss, Zhenyu Lai, Tom Longwell, Tina Marsh, Maryam Saeedi, Connan Snider, and Hao Teng provided excellent research assistance. We gratefully acknowledge support from the NSF (grant no. SES-0924371).

1. Source: World Trade Organization.



*The Quarterly Journal of Economics* (2011) 126, 1173–1211. doi:10.1093/qje/qjr026.
Advance Access publication on July 16, 2011.

We take as a case study the design of time incentives in award procedures for highway procurement. Highway repair makes for a good case study, because it generates significant negative externalities for commuters through increased gridlock and commuting times. For example, US 101 is an important highway through Silicon Valley, carrying over 175,000 commuters per day. If a highway construction project results in a 30-minute delay each way for commuters on this route, the daily social cost imposed by the construction would be 175,000 hours. Valuing time at $10 an hour, this implies a social cost of $1.75 million per day. But in standard highway contracts, contractors have poor incentives to internalize this externality. For example, highway contractors in California are given relatively generous deadlines, and even then are only penalized with damages of up to $40,000 a day if late. Given these weak incentives, it is likely that the observed completion times will be inefficiently slow.

Recently, state highway departments in the United States have started to experiment with innovative contract designs that provide explicit time incentives. The most sophisticated is a scoring auction design, called "A+B bidding." Here, contractors submit a dollar bid for labor and materials, the "A" part, and a total number of days to complete the project, the "B" part. The bids are scored using both the A and the B bid and the project is awarded to the contractor with the lowest score. The winning contractor may also receive incentive payments (disincentives) for completing the project earlier (later) than the days bid. Standard highway contracts are "A-only" contracts because they do not weight project completion time in selecting the winning contractor.

In this article, we evaluate this scoring auction design both theoretically and empirically. We start by building a simple model of A+B contracts that subsumes standard A-only contracts and other commonly used contract designs as special cases. We characterize equilibrium bids and project completion times. Intuition suggests that if each day taken causes delays to commuters of $10,000, then the right policy is to "tax" contractors $10,000 for each day they take. This forces them to internalize the externality. We show that the time weight in the A+B scoring rule acts like a tax, so this contract design can achieve efficient outcomes. By contrast, the standard contract design amounts to a "quota" policy, and will often result in an inefficiently slow project completion time.

Armed with these insights, we move on to the heart of the article: an analysis of over 1300 contracts awarded by the California Department of Transportation (Caltrans) between 2003 and 2008. Our data include detailed information on the contract provisions, bids, and time taken. Examining the A+B bid data, we see that on average, contractors bid to complete the work much quicker than the target specified in the design, around 60% of the engineer's days estimate. Multiplying a project-specific estimate of the daily social cost to commuters by the days saved from this acceleration, we get an average reduction in the negative externality to commuters of $6.1 million per contract. We also compare the winning bids in A+B contracts to a control group of standard contracts with similar observables. The winning bid is on average $1.5 million higher in A+B contracts, so the policy raises commuter welfare by substantially more than the change in procurement costs.

We also want to estimate the welfare gains from this policy and counterfactual alternatives. To do this, we need to recover the marginal costs contractors incur in accelerating construction. This is basically a supply curve, and we estimate it from exogenous variation in the user costs offered in different A+B contracts. The main source of variation is policy differences across districts. Our estimated supply curve is convex. This implies that small reductions in completion time are reasonably cheap, but large reductions are expensive and require far bigger incentives. So a cost-effective policy for Caltrans would be to award more contracts by A+B auction than is current practice, but give weaker time incentives.

To test this theory, we estimate auxiliary models of auction participation and bidding that allow us to account for selection into the auction and for selection out (who wins the contract). We use these models together to examine counterfactual scenarios. We find that the welfare gain from switching all contracts from the standard design to the efficient A+B design is large, nearly 22% of the total contract value (for these contracts, $1.14 billion). However, this policy substantially raises contractor costs and these costs will be passed through to Caltrans, which faces budget constraints. To address this concern, we show that a policy with smaller time incentives could achieve most of the gains ($1.03 billion) without higher total contractor costs than under the current policy. This motivates our main conclusion, which is that including time incentives in all highway procurement projects through more sophisticated contract design would substantially raise social welfare.

The main threat to our analysis is endogeneity, both in terms of A+B assignment and assignment of user costs. In this we are hampered by the absence of a clean quasi-experimental research design. Although we can show that A+B assignment is driven primarily by estimates of the social costs of construction, and not by the specifics of the construction project itself, we cannot rule out a correlation between the size of the externality and acceleration costs. To partially address this, we perform two robustness exercises in the Online Appendix. One tackles the program evaluation from another angle, by using a regression discontinuity design approach. Though the estimates are substantially less precise, they are similar in magnitude and confirm the benefit of the existing A+B policies. The second carries out additional counterfactual simulations under alternative assumptions on the elasticity of acceleration supply and finds similar conclusions to those in the main text.

This article is related to four main literatures. There is a literature in engineering on the role of time incentives in highway procurement (see for example Arditi and Khisty 1997; Herbsman, Tong Chen, and Epstein 1995), as well as a recent report from the National Cooperative Highway Research Program (Fick et al. 2010). These papers take more of a descriptive approach than we do here. The second is the large theoretical literature on regulation and optimal procurement (see for example Weitzman 1974; Laffont and Tirole 1987; Manelli and Vincent 1995; Branco 1997). In analyzing A+B auctions, we follow the existing literature on scoring auctions starting with Che (1993) and extended in Asker and Cantillon (2008). We focus on welfare-maximizing, rather than cost-minimizing contract design, avoiding complex multidimensional screening issues (see Asker and Cantillon 2010 on optimal scoring auctions).

Third, there is an empirical literature on auctions with multidimensional attributes. Our article is the first to structurally analyze scoring auctions. Krasnokutskaya and Seim (forthcoming) and Marion (2007) consider outcomes from other mechanisms where the contract is not awarded solely based on price. Athey and Levin (2001) and Bajari, Houghton and Tadelis (2007) analyze multidimensional bidding in timber auctions and highway procurement, respectively, emphasizing how the bids determine ex post behavior. Finally, our article is related to earlier work on analysis of highway contracts (see Porter and Zona 1993; Hong and Shum 2002; Bajari and Ye 2003; Jofre-Bonet and Pesendorfer 2003; Marion 2007; Silva et al. 2008; Einav and Esponda 2008; Gil and Marion 2009; Li and Zheng 2009; Lewis and Bajari 2010; Krasnokutskaya forthcoming).

Section II gives an overview of the procurement process. Sections III, IV, and V contain the theoretical, empirical, and counterfactual policy analyses. Section VI concludes.

## II. Highway Procurement in California

Highway procurement in California takes place in three phases, as illustrated by Figure I. Once a need for construction has been identified, Caltrans designs the project. The design engineer will also develop an estimate of the project cost ("the engineer's estimate") and a target number of working days for project completion ("the engineer's days estimate"). Based on advice from the traffic operations unit, the design specifies a maximum number of lanes that can be closed at each phase of the project and during which hours of the day closures may occur. Last, the engineer will make a recommendation as to whether a standard or A+B contract design should be used, usually based on the size of the project and the projected negative externality. This recommendation must be approved by headquarters.

Once a decision has been made, the terms of the contract are summarized in a set of special provisions. In a standard design, the provisions specify that the contract will be awarded to the lowest responsive bidder, and the winning firm will have to complete the contract within the engineer's days estimate. In the A+B design, the contract is awarded based on a scoring rule, and the winning firm must complete the contract within the number of days they bid. Penalties are charged for late completion. These penalties are equal to the user cost in A+B contracts and are set using a statewide formula in standard contracts.

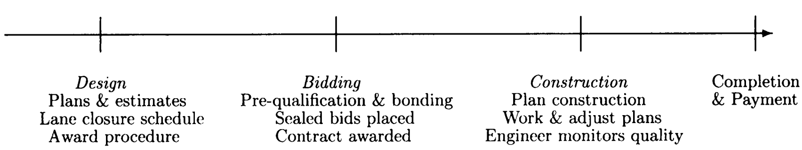


FIGURE I

Timing of Events in the Highway Procurement Process

At this point, the project is advertised and interested parties can obtain copies of the plans and special provisions. In California, bidders are prequalified by having a contractor license for that kind of work and by submitting a bond equal to 10% of their bid. This bond will be forfeited if they win the contract and then don't complete it (alternatively the bond issuer, typically a third party, may pay someone else to complete the work). Next, the contractors bid on the contract, according to the bidding rules laid out in the special provisions. In the case of A+B contracts, if the days bid seems unrealistic, the winning contractor may be required to provide a convincing project timeline for on-time completion, otherwise Caltrans may seek to disqualify their bid. The final "contract days" is equal to the engineer's days in a standard contract and the days bid in an A+B contract.

Once the contract is awarded, the construction phase starts. The contractor must plan how to structure the various distinct activities, such as excavation or grading, that make up the construction project. They must operate within the constraints of the lane closure schedule. For A+B contracts, the construction plan may have to be worked out before bidding. Accelerated construction may require extra shifts or the hiring of additional capital. Next, the construction begins. During the process, the project engineer conducts random checks on the quality of the materials and monitors whether everything is completed according to the plan specifications. Because highway construction is generally a pretty homogenous good, project engineers have built up considerable expertise in testing for deficiencies in construction and are skilled at assessing quality. The engineer also designates days on which environmental conditions make work difficult as "weather days," and as "other days" those on which the contractor cannot work through no fault of his own (for example, a general strike). These days do not count toward the contract deadline. Still, productivity shocks may affect the rate at which any activity is completed, and contractors keep track of their progress and amend plans if necessary. At the end of the process, the contractor is paid the amount they bid less any damages assessed for late completion.

## III. THEORY

Before turning to the data, it will be useful to specify a simple model to frame the empirical analysis. Essentially, the problem faced by Caltrans is twofold: on one hand, they want to award highway contracts to the most cost-effective or efficient bidder. For this, an auction mechanism is preferred approach. On the other hand, they want to regulate an externality when they don't know how expensive it is for contractors to accelerate construction.[2] If the available policy tools were either a quota or a tax on the time to completion, this would correspond to the problem analyzed in Weitzman (1974).

In practice, these two problems are jointly solved by first specifying a set of time incentives as part of the contract, and then awarding that contract, typically by auction. We refer to the combination of time incentives plus award mechanism as a contract design. To analyze the theoretical performance of the A+B and standard contract designs, we now set up a model of an A+B auction that subsumes the standard design as a special case:

*Auction Format.* $n$ risk-neutral contractors bid on a highway procurement contract. A bid is a pair $(b, d^B)$ indicating the base payment $b$ received by the winning contractor, and the contract days $d^B \in [0, d^E]$. The upper bound $d^E$ is the project engineer's estimate of the maximum time the project should take to complete. The bids are ranked according to the scoring rule $s = s(b, d^B) = b + c_U d^B$, and the contract is awarded to the contractor with the lowest score. The constant $c_U \geq 0$ in the scoring rule is known as the *user cost*. The contract also specifies ex post time incentives: a per day incentive $c_I \geq 0$ and disincentive $c_D > 0$ that are applied when the winning contractor completes the job before or after the contract days. We restrict our analysis to the case $c_I \leq c_D$, which holds for all of the contracts we examine. The three parameters $(c_U, c_I, c_D)$ define the incentive structure.

*Payoffs and Types.* Losing bidders receive a payoff normalized to 0. The winning contractor has a payoff given by:

$$\pi(b, d^B, d^T; \theta) = b + 1(d^B > d^T)(d^B - d^T)c_I - 1(d^B < d^T)(d^T - d^B)c_D - c(d^T; \theta), \tag{1}$$

where $d^T$ is the actual days taken to complete the contract and $c(d^T; \theta)$ are the costs incurred. Profit is bid plus incentive payments (possibly negative) less costs.

2. In this article we focus on the commuter externality as a reason to accelerate construction. There may be other reasons to do so—for example, a new highway has no usage value until it is built.

The cost function $c(d^T;\theta)$ is "long-run," in the sense that it represents the cost of completing the contract in $d^T$ days, for a contractor of type $\theta$, *given optimal input choices*.[3] We assume a textbook long-run cost curve, U-shaped in $d$ for all $\theta$, with a minimum at the efficient scale of construction (which is presumably close to the engineer's estimate). Contract acceleration is costly because it requires working at an inefficiently large scale. The type $\theta$ reflects contractor-specific cost parameters, such as their expertise with working on a tight schedule, their relationships with subcontractors and input suppliers, and their current managerial capacity.[4] We assume that each contractor $i$ draws their cost parameter $\theta_i$ from some contractor-specific distribution $F_i$. This is an independent private values framework.

*Strategies and Equilibrium.* A (Bayes-Nash) equilibrium of the game is a set of bidding strategies $(\beta_1(\theta), \cdots, \beta_n(\theta))$ of the form $\beta_i(\theta) = (b_i(\theta), d_i^B(\theta))$, that are mutual best responses; and a completion time $d^T(d^B;\theta)$. Notice that we assume that firms face no uncertainty about their type and can choose their completion time. This simplifies the analysis and seems reasonable because Caltrans accounts for all unavoidable delays through weather and other days. As evidence that completion time is under the contractor's control, 52% of the A+B contracts in our data are completed exactly on time. This does not rule out ex post productivity shocks and a need for adaptation, but as Lewis and Bajari (2010) show, accounting for ex post shocks requires more thought as to the ex post incentives $c_I$ and $c_D$, without changing most of the ex ante analysis presented here.[5]

*Social Welfare and Efficiency.* Social welfare is given by $W(d^T;\theta) = V - c(d^T;\theta) - d^T c_S$. It reflects the total social value of the highway project $V$, less the contractor's private costs, less the social

3. Once construction starts and inputs are hired, the contractor will face a "short-run" cost function $c(d;\theta,K)$ for fixed inputs $K = K(d;\theta)$, but this is not the relevant curve at the bidding stage.

4. For example, the construction company C.C. Myers repaired an important ramp between I-80 and I-580 near San Francisco after an explosion, doing so in 17 days as opposed to the 50 estimated. In an interview, the owner mentioned as important factors for the speedy completion a collaboration with a steel fabricator to get girders made quickly, an ambitious plan that allowed for work to be done while still waiting for some of the inputs, and his crews working all day in 12-hour shifts Pogash (2007).

5. Introducing risk aversion in addition to uncertainty would, however, complicate the analysis.

costs of the construction. The social costs are assumed to be linear in the days taken, with the daily social cost equal to a constant $c_S$. This seems like the right approximation, though the theory extends easily to more complicated social cost functions.

We say that a contract design is *ex-post efficient* if the incentive structure is such that the completion time $d^T(d^B;\theta)$ is welfare maximizing for all types $\theta$. We say that a contract design is *ex-ante efficient* if the winning bidder is always the bidder who generates the highest social welfare $W(d^T;\theta)$ in equilibrium. These notions decouple regulating the winning bidder (ex post efficiency) from choosing that bidder (ex ante efficiency).

*Standard Contracts.* The standard contract design is a special case.[6] The contract is awarded solely on the bid amount, and the design engineer sets $d^E$. There are no positive incentives ($c_I = 0$), and the disincentives $c_D$ are called liquidated damages, set by a statewide formula. This corresponds to our model with the constraint that bidders bid $d^B = d^E$.

We proceed in two parts. First we analyze how effective the two designs are in regulating the externality, and then we look at whether the auction mechanism is ex ante efficient.

*Efficient Regulation.* The incentive scheme of the standard contract design is ex post inefficient given the constant externality. To see this, consider the left panel of Figure II. The downward-sloping curves are three possible marginal private cost of acceleration curves, corresponding to three different types for the winning contractor. As depicted, all types have positive costs of acceleration at the engineer's days estimate, and all would prefer to operate at a lower scale and complete more slowly. But they are penalized at a rate of $c_D$ when late, giving them an incentive for on-time completion. By contrast, there is no bonus for being early, which implies that time incentives are discontinuous at $d^E$. This design effectively amounts to a quota of $d^E$ days, where the penalty for exceeding the quota is $c_D$. Facing these incentives, all three types will complete exactly on time. But because efficiency requires that different types complete at different times to equate their private marginal costs with the social benefits of acceleration, this design is inefficient.

6. We omit analysis of two other important contract designs with time incentives: lane rental and incentive/disincentive contracts. They are also special cases of our general model; details available on request.

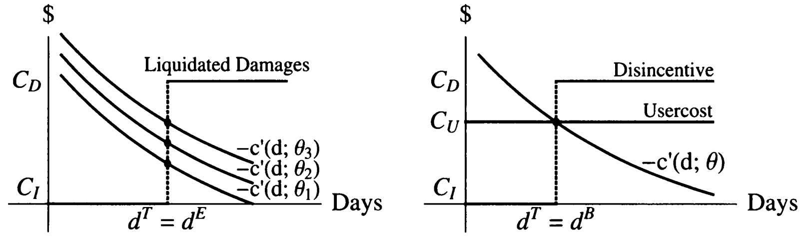


FIGURE II

Completion Time in Standard and A+B Contracts

Both panels show the marginal private cost of acceleration curve, $-c'(d;\theta)$. The left panel shows a standard contract, with damages charged after the specified completion time $d^E$. The optimal completion times vary with the type $\theta$, but all types choose to complete at $d^E$, which is inefficient. In the right panel, the contractor bids to complete where the user cost intersects his acceleration cost curve, and completes on time because of the incentive structure. If the user cost equals the social cost, this is efficient.

Instead, the contractor should be forced to internalize the externality imposed on commuters by construction. The simplest way to do this is a tax of $c_S$ a day. The A+B design looks like a quota, but behaves like a tax. Consider the right panel of Figure II. Because $c_I < c_D$, the contractor faces discontinuous incentives at $d^B$, like a quota. But the contractor can choose $d^B$ in the auction. The scoring rule specifies the trade-off: each extra day bid forces the contractor to lower their bid by $c_U$ to maintain the same score. This essentially amounts to a tax on each day of $c_U$. Not surprisingly then, if the user cost is set equal to the social cost $c_S$, this creates the right incentives for ex post efficiency.

One complication is that the contractor is not bound by the days bid, except insofar as the contract enforces compliance. Whenever $c_D < c_U$, the *effective* tax is only $c_D$, and so the contractor will bid zero days but complete where the marginal cost of acceleration equals $c_D$.[7] This design detail is important in practice: in some of the first A+B contracts they let, Caltrans set $c_D < c_U$, and the contractors bid just one day. As a consequence, in all the recent contracts they have issued, Caltrans has set $c_I < c_U = c_D$. Overall, for ex post efficiency in the A+B design, it is sufficient

7. Bidding to complete one day earlier than actually planned earns $c_U$ from the scoring rule, and costs $c_D$ in damages, and thus is always desirable with those incentives.

that the effective cost of delay is $c_S$, which is best accomplished by setting $c_U = c_S$ and $c_I \leq c_U \leq c_D$.[8]

*Ex Ante Efficiency.* The next question is whether the auction mechanism awards the contract to the contractor who will maximize social welfare. As Asker and Cantillon (2008) show, in a scoring auction the equilibrium strategies of bidders are functions of their pseudo-costs, defined here as:

$$P(\theta_i) = c(d^T, \theta_i) + IP(d^T, d^B) + c_U d^B, \tag{2}$$

where $d^B$ and $d^T$ are optimally chosen in the manner described, and $IP(d^T, d^B)$ denotes any incentive payments that will be paid or charged. The pseudo-cost has three parts: contractor costs given the construction plan; the incentive payments received under that plan; and the B-score $c_U d^B$. This one-dimensional pseudo-cost is a sufficient statistic for the bidder's type $\theta$.

Having transformed the types into pseudo-costs, we can then apply standard results from the auction literature. Provided the bidders are symmetric, the auction mechanism will award the contract to the bidder with the lowest pseudo cost. Now, if the contract is ex post efficient, the pseudo-cost is equal to the social cost of the project, and so awarding it on the basis of pseudo-cost yields ex ante efficiency. More generally, even when the contract design is not ex post efficient, it may still be best to award based on pseudo-cost. This is true of standard contracts if incentives are appropriately set. Suppose, for example, that all bidders have positive benefits of delay up until the engineer's target date. Then since there are no bonuses for being early, all contractors will complete either on time or late. By setting $c_D = c_S$, the procurer can force contractors to internalize the social costs of late completion as part of their pseudo-cost. Then awarding the contract on the basis of pseudo-cost selects the contractor who maximizes welfare subject to the constraint that they cannot finish early—a second best result—and this is ex ante efficient.

In summary, the problem of regulating the externality and awarding the contract can be largely decoupled. By taxing the ex-

8. The optimality of the "tax" approach hinges on the fact that the daily social costs are linear. In general, the scoring rule should match the social cost function. For example, suppose that for most of the summer a highway is not busy, with a daily social cost of \$2,000, but during the August holiday season the social cost leaps to \$10,000 a day. Then for ex post optimality, each day bid up to August 1 should add \$2,000 to the score, but each day thereafter should add \$10,000.

ternality through a weight in the scoring rule, the contract design is made ex post efficient. By awarding the contract via auction, we achieve the usual gains from competition among bidders.

*Cost of time incentives.* Later in the article, we consider how much the use of A+B rather than standard contracts increases procurement costs. It would be nice to have a theoretical prediction to take to the data. Intuitively, it should be quite costly, as high-powered time incentives generate contract acceleration, and the acceleration costs should be passed through in the form of higher bids. Moreover, the emphasis on time in A+B auctions means that an expensive but quick bidder could be favored over a cheap and slow one, which would rarely happen in a standard auction. This too is costly. Still, to make concrete statements about the relationship between costs and bids, one needs to know something about markups. These could go up or down.

For example, suppose there were two contractors competing for business. The first uses cheap unskilled labor, completes jobs at a slow rate, and finds acceleration costly. The second uses more skilled labor and is generally quite expensive, though it can cheaply accelerate construction. Then the first company would be able to maintain a high markup in auctions for standard contracts, due to the cost asymmetry, but in A+B auctions that cost advantage would diminish and its markup would fall. On the other hand, if the first company were both cheap and quick, the A+B design would magnify their competitive advantage, and their markup would rise. The conclusion is that the relationship between costs and bids is complex and not easy to deduce cost changes from bid changes without knowing something about the correlation between "quick" and "cheap."

## IV. Program Evaluation

The theory suggests how contracts should be designed to maximize social welfare. In the remainder of the article, we examine the A+B contract design in practice, using data from contracts let by Caltrans during the period 2003–2008. Our data set is rich, including detailed data on the contract provisions, bids, and outcomes for both standard and A+B contracts. This enables us to answer two practical questions: Do A+B contracts work well in practice? And could Caltrans adopt better policies? We answer the first using the language and methodology of the program evaluation literature. For the second we build, estimate, and simulate counterfactual outcomes using a structural model of contractor behavior.

### IV.A. Data

Our data set was constructed using publicly available data from the Caltrans website. We collected contract, bid, and payments data for all contracts that were let in the period 2003–2008.[9] From these data, we know the contract provisions relating to time and lane closure restrictions; a description of the contract location, type of work, funding source, and engineer's estimates; all the bids, bidder identities, and locations; and the payments made to the winning contractor during the course of the job. The final payment files also give a breakdown of the working days, weather days, and other days used over the course of the project.

Because we are interested in comparing standard and A+B contracts, we narrowed the scope of our data by dropping contracts with different designs. We also chose to focus on a subset of contracts which seemed a priori to potentially require lane or shoulder closure: barrier construction, bridge repair or resurfacing, new lane or ramp construction, road rehabilitation, slope work, and widening/realignment. The A+B design is very rarely used outside of these categories. Likewise, we restricted the analysis to those Caltrans districts that use the A+B design with some frequency (they are SF Bay Area (4), Fresno (6), Riverside/San Bernadino (8), San Diego (11), and Orange County (12)). Of these, district 4 is by far the most frequent user of the format and plays an important role in our analysis.

We augmented this data with traffic volumes and the percentage of trucks at each of the contract locations. This enabled us to construct a simple measure of the negative externality to commuters during project construction for each project $j$:

$$\text{(3)} \qquad \textit{Social Cost}_j = \textit{Delay}_j \times \textit{Time Value}_j \times \textit{Traffic}_j.$$

For time value, we use a weighted average of a value for cars ($12 per vehicle hour) and for trucks ($28 per vehicle hour), where the weights are contract-specific. These are the values used by Caltrans in their own calculations in 2008. To estimate the delay, we assume that traffic will be slowed from 55 mph (the speed limit

9. By "let," we mean that the bids were opened on a date in that period. For a much more detailed description of the data, see the Online Data Appendix.

on a typical California freeway) to 35 mph over the full length of the construction zone, or 5 miles, whichever is shorter. In most construction zones, a slowdown of at least this magnitude is to be expected either due to actual lane closures or to traffic control. These assumptions are chosen to be conservative, and imply that we will never project a delay of more than 3:11 minutes per commuter on any project.[10] The social cost is then arrived at by multiplying the traffic, delay, and average time value. We treat this variable as data rather than an estimate throughout the analysis.

Table I summarizes the contract characteristics for different subsamples of the data. Looking at the second column, notice that the social costs we have estimated using Equation 3 are more than three times larger than those assigned as usercosts by Caltrans. Initially we found this puzzling, as we had thought that Caltrans policy was to set the user cost equal to the social cost, indicating that our simple estimates were too high. Subsequently we learned that district 4 sets them based on a standardized statewide formula for liquidated damages, which depends on the engineer's estimate, engineer's days, type of work, and projected office expenses of the project engineer, rather than on traffic or projected delays. This tends to understate the daily welfare loss to commuters. It is not clear why there is also a large gap for the other districts, but given how conservative our social cost calculations have been, we proceed under the assumption that they are a lower bound on the true social costs.[11]

### *IV.B. A+B Assignment and Identification*

We now turn to the question of whether the A+B design works well in practice. The trade-off is between completion time and cost. To quantify this, we take a standard program evaluation approach, comparing the outcomes of A+B contracts (the "treated" group) with those from a comparable group of standard contracts (the "control" group). Our goal is to estimate the difference in expected outcomes given A+B versus standard assignment, for the A+B contracts—an average treatment effect on the treated

10. We also used Google Maps to calculate a detour route for a typical commuter around the construction zone, but in all cases the detour caused a delay of more than 3:11 minutes and so these data were discarded.

11. It could be that Caltrans assumes no negative externality during hours when lane closures are not permitted (though we have been told this is not the case), or that sometimes they set the user cost below their social cost estimate to avoid the weight on time being "too large" relative to contract size.

TABLE I

SUMMARY STATISTICS FOR SELECTED CALTRANS HIGHWAY CONSTRUCTION PROJECTS, 2003–2008

| | All Contracts | | Eligible Only | | Eligible & Completed | |
|---|---|---|---|---|---|---|
| | Standard | A+B | Standard | A+B | Standard | A+B |
| Engineer's Estimate ($M) | 4.566 | 21.88† | 21.50 | 22.90 | 13.88 | 15.51 |
| | (14.82) | (29.20) | (31.14) | (29.61) | (26.40) | (12.64) |
| Winning Bid ($M) | 4.084 | 19.88† | 19.18 | 20.79 | 13.16 | 13.81 |
| | (14.29) | (28.21) | (30.74) | (28.66) | (25.63) | (11.98) |
| Winbid / Engest | 0.915 | 0.913 | 0.890 | 0.908 | 0.934 | 0.912 |
| | (0.289) | (0.197) | (0.222) | (0.198) | (0.232) | (0.204) |
| Number of Bidders | 5.067 | 5.463 | 5.771 | 5.487 | 4.956 | 5.356 |
| | (2.796) | (2.565) | (2.939) | (2.574) | (2.571) | (2.318) |
| Engineer's Days Estimate | 121.6 | 313.6† | 366.8 | 326.1 | 260.1 | 278.5 |
| | (181.8) | (202.8) | (311.5) | (200.3) | (234.1) | (144.8) |
| Daily Traffic (thousands) | 76.28 | 117.8† | 93.00 | 120.0† | 81.93 | 122.0† |
| | (84.28) | (74.06) | (83.11) | (74.12) | (79.79) | (76.77) |
| Lane Closure Fraction | 0.488 | 0.449† | 0.492 | 0.444† | 0.490 | 0.431† |
| | (0.140) | (0.109) | (0.146) | (0.106) | (0.144) | (0.0973) |
| Reopening Penalty | 0.400 | 0.825† | 0.486 | 0.829† | 0.397 | 0.797† |
| | (0.491) | (0.382) | (0.502) | (0.379) | (0.493) | (0.406) |
| Social Cost ($K) | 34.38 | 50.74† | 43.66 | 50.79 | 42.85 | 53.96 |
| | (47.06) | (46.76) | (45.09) | (46.86) | (46.50) | (50.40) |
| Usercost ($K) | – | 14.81 | – | 15.22 | – | 12.48 |
| | | (15.37) | | (15.64) | | (9.632) |

TABLE I
(CONTINUED)

| | All Contracts | | Eligible Only | | Eligible & Completed | |
|---|---|---|---|---|---|---|
| | Standard | A+B | Standard | A+B | Standard | A+B |
| | Indicator variables for types of work | | | | | |
| Bridge Repairs | 0.0430 | 0.0875 | 0.0857 | 0.0921 | 0.0441 | 0.0678 |
| | (0.203) | (0.284) | (0.281) | (0.291) | (0.207) | (0.254) |
| Bridge Resurfacing | 0.0175 | 0.0625† | 0.0190 | 0.0658 | 0.0294 | 0.0847 |
| | (0.131) | (0.244) | (0.137) | (0.250) | (0.170) | (0.281) |
| Construction | 0.0557 | 0.138† | 0.105 | 0.145 | 0.0588 | 0.153 |
| | (0.230) | (0.347) | (0.308) | (0.354) | (0.237) | (0.363) |
| Rehabilitation | 0.556 | 0.375† | 0.352 | 0.355 | 0.441 | 0.407 |
| | (0.497) | (0.487) | (0.480) | (0.482) | (0.500) | (0.495) |
| Slope | 0.0462 | 0.0375 | 0.0667 | 0.0395 | 0.0882 | 0.0339 |
| | (0.210) | (0.191) | (0.251) | (0.196) | (0.286) | (0.183) |
| Widen and Realign | 0.132 | 0.225† | 0.276 | 0.237 | 0.235 | 0.186 |
| | (0.339) | (0.420) | (0.449) | (0.428) | (0.427) | (0.393) |

TABLE I
(CONTINUED)

| | All Contracts | | Eligible Only | | Eligible & Completed | |
|---|---|---|---|---|---|---|
| | Standard | A+B | Standard | A+B | Standard | A+B |
| Outcomes from completed contracts | | | | | | |
| Contract Days | | | | | 260.1 | 171.4† |
| | | | | | (234.1) | (114.4) |
| Working Days | | | | | 234.8 | 171.1† |
| | | | | | (210.1) | (115.0) |
| Weather Days | | | | | 74.06 | 80.85 |
| | | | | | (71.91) | (81.44) |
| Other Days | | | | | 8.132 | 11.36 |
| | | | | | (23.77) | (23.51) |
| Quality Deductions ($K) | | | | | 4.521 | 3.650 |
| | | | | | (14.72) | (6.897) |
| Observations | 628 | 80 | 105 | 76 | 68 | 59 |

*Notes.* Summary statistics for different subsamples, by A+B status. Means are reported, with standard deviations in parentheses. "Eligible" refers to contracts of over 100 engineer's days in district 4, or over $5M in engineer's estimate in other districts. "Completed" indicates construction was finished as of July 1, 2009. "Lane Closure Fraction" is the fraction of the total lanes on the highway that the contractor is allowed to close during construction hours. "Re-opening penalty" is a binary variable indicating if the contract specifies a monetary penalty for late re-opening of a lane at the end of construction hours. "Social Cost" is an estimate of the daily negative externality to commuters (see text). "Usercost" is the weight on time in the A+B scoring rule (see text). "Barriers" is the omitted type of work. "Quality Deductions" are penalties assessed by Caltrans during the course of the contract for quality violations (see Online Data Appendix). Significant differences between the standard and A+B groups at the 5% level are denoted by a † superscript in the A+B column.

(ATT). First, though, we need to analyze how the treatment was assigned.

We asked officials in a number of Caltrans districts how they decided which contracts should be auctioned using the A+B mechanism. District 4 indicated they used the A+B design whenever the engineer's days estimate exceeded 100 days. All other districts said they followed a rule mandated by headquarters, under which a project should be assigned A+B status if the engineer's estimate was over $5 million and if their estimate of the daily social cost was over $5,000. In all districts, there is room for exceptions—for example to use the design when there were other political/economic issues that made timely completion important, and to disqualify the design when the contract had the potential for third-party problems, or when approval was denied by headquarters.[12] As we show in the Online Appendix, the data are consistent with these stated policies.

This suggests good treatment and control groups. The treatment group is all size-eligible A+B contracts, and the control group is all size-eligible standard contracts, where size-eligible means over $5 million outside of district 4 or over 100 days in district 4. These contracts should differ only for the largely idiosyncratic reasons outlined. The observable characteristics of the size-eligible A+B and standard contracts are summarized and compared in the third and fourth columns of Table I. As shown, the groups are generally balanced on the observables.[13] The only statistically significant differences are related to the social cost of construction: on busy roads, A+B assignment is preferred, lane closures are limited, and penalties are charged for late reopening.

Our identification strategy hinges on the independence of assignment and the outcomes of interest, conditional on observables and size eligibility. Here this amounts to assuming that for a given type of job, contract size, location, and year, the omitted factors that determine completion time and the winning bid are orthogonal to the social costs, political concerns, third-party issues, and so on that govern assignment. This seems reasonable, since these

12. Third-party problems arise, for example, when a utility company needs to evacuate a piece of land during some phase of the construction. Then if the company is late in fulfilling its obligations, the contractor cannot proceed and can claim compensation from Caltrans for the delay. This is presumably more problematic when the contractor is on a tight schedule.

13. The two groups also appear to "overlap" well in terms of the marginal distributions of the observables.

TABLE II
POLICY EVALUATION OF A+B CONTRACT DESIGN

| | Eligible Contracts | | | Eligible & Completed | | |
|---|---|---|---|---|---|---|
| | Log Winning Bid (1) | Contract Days/ Engdays (2) | Log Winning Bid (3) | Working Days/ Engdays (4) | Total Days/ Engdays (5) | Quality Deductions Engest (6) |
| A+B Dummy | 0.075** | −0.395*** | 0.057 | −0.329*** | −0.351*** | −0.002 |
| | (0.033) | (0.019) | (0.041) | (0.031) | (0.098) | (0.136) |
| Log Engineer's Estimate | 0.933*** | | 0.918*** | 0.001 | −0.053 | −0.084 |
| | (0.018) | | (0.024) | (0.018) | (0.046) | (0.080) |
| Log Engineer's Days | 0.109*** | | 0.111** | −0.008 | | 0.281* |
| | (0.034) | | (0.044) | (0.034) | | (0.148) |
| Log Daily Traffic | 0.017 | | 0.016 | −0.010 | −0.017 | 0.084 |
| | (0.014) | | (0.018) | (0.014) | (0.042) | (0.059) |
| Lane Closure Fraction | 0.129 | | 0.084 | −0.025 | −0.302 | 0.273 |
| | (0.117) | | (0.150) | (0.115) | (0.356) | (0.497) |
| Reopening Penalty | −0.040 | | −0.043 | 0.038 | 0.060 | −0.264 |
| | (0.040) | | (0.051) | (0.039) | (0.122) | (0.170) |
| District/Work/Year FE's | yes | no | yes | yes | yes | yes |
| $R^2$ | 0.9759 | 0.7129 | 0.9706 | 0.5990 | 0.3777 | 0.2079 |
| $N$ | 181 | 181 | 127 | 127 | 127 | 127 |

TABLE II
(CONTINUED)

| | Eligible Contracts | | | Eligible & Completed | | |
|---|---|---|---|---|---|---|
| | Log Winning Bid (1) | Contract Days/ Engdays (2) | Log Winning Bid (3) | Working Days/ Engdays (4) | Total Days/ Engdays (5) | Quality Deductions Engest (6) |
| ATT Winning Bid ($M) | 1.496 | | 0.994 | | | |
| | (0.640) | | (0.425) | | | |
| ATT Commuter Welfare ($M) | | 6.096 | | 5.675 | | |
| | | (0.512) | | (0.477) | | |
| ATT (CWelfare - Winbid) ($M) | | 4.599 | | 4.680 | | |
| | | (0.785) | | (0.573) | | |

*Notes.* In columns (1) and (2), the estimation sample is all A+B eligible contracts. The dependent variable in column (1) is log winning bid, and in column (2) it is contract days divided by the engineer's days estimate. "Contract Days" equals the days bid in an A+B auction, and the engineer's days otherwise. (1) and (2) are estimated jointly by seemingly unrelated regressions (SUR). Columns (3) and (4) are also estimated jointly by SUR on the subsample of completed and eligible contracts, with the dependent variables being log winning bid and working days taken divided by engineer's days, respectively. Columns (5) and (6) are estimated jointly by SUR on the same subsample; the dependent variable in (5) is total days taken (working days + weather days + other days) divided by engineer's days, and in (6) it is quality deductions × 1000 divided by the engineer's estimate. District, year, and type of work fixed effects are included except in (2). The ATT Winning Bid is an estimate of the expected difference between the winning bid under A+B versus standard assignment, for an average A+B contract. The counterfactual standard bid is computed for each A+B contract as the product of the winning bid and $E[e^{-\alpha}]$, where $\alpha$ is normally distributed with mean and standard deviation given by the A+B dummy coefficient and its standard error. The ATT Commuter Welfare is the expected change in (contract, working) days multiplied by the social cost. Standard errors on the treatment effects are obtained by the delta method. Significance levels are denoted by asterisks ($^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$).

factors are outside the scope of the construction work and don't appear to directly affect it. Nonetheless, we must concede that there is a risk of selection on unobservables. We respond to this concern in the robustness discussion.

### *IV.C. Estimation Approach and Results*

We take a simple estimation approach, running orindary least squares (OLS) regressions of outcomes on a host of controls and a dummy for A+B assignment (the treatment). Two different samples of contracts are used. For two of the regressions, we use the set of size-eligible contracts, whereas for the remainder we use the subset of size-eligible and completed contracts. The latter sample allows us to look at the realized ex post outcomes.

The results are shown in Table II. The first and third columns are results from regressions of log winning bid on the covariates shown, for the eligible and completed samples, respectively. We estimate an increase in the winning bid of between 5.7% (completed) and 7.5% (eligible).[14] What about completion time? In column (2) we see that the ratio of contract days to engineer's days is 39.5% lower for A+B contracts. So on average contractors promise to complete the contract around 40% earlier. They also follow through. For the completed contracts, we see that the ratio of working days taken to engineer's days is 33% lower for A+B contracts. The difference between the promised and realized gain in acceleration time is entirely accounted for by the fact that standard contracts typically finish 7% early, whereas A+B contracts finish exactly on time.

One concern is that the A+B contracts perform well in reducing the working days taken, but do poorly on other dimensions—for example, by taking additional weather days or by shirking on quality. This doesn't appear to be the case. In column (5), we look at the ratio of total days (working days plus weather and other days) to engineer's days and show that A+B contracts take 35% fewer days in total. Column (6) indicates that there is no difference in the quality deductions charged on A+B versus standard contracts, which suggests that construction quality is the same in both cases.[15]

14. Strong, Tometich, and Raadt (2005) find a similar cost increase of 7.5% for A+B contracts in Minnesota.

15. Fick et al. (2010) perform a similar exercise for a sample of 455 standard and 22 contracts with time incentives from a particular state highway agency in 2007 and also find no statistically significant differences.

To analyze the trade-off in more economically meaningful terms, we convert the time savings into dollars by multiplying the estimated number of days saved for each contract by our social cost measure for that contract. For the eligible contracts, we use the difference in contract days (i.e., the ex ante measure of column (2)), but for the completed contracts we use the difference in working days taken (i.e., the ex post measure of column (4)). We then average across contracts to get an ATT. The bottom part of Table II shows the ATT estimates. On average, A+B assignment increases the winning bid by $1 million (completed) to $1.5 million (eligible). Commuters gain far more, between $5.6 million (completed) and $6 million (eligible), implying a statistically significant difference of around $4.6 million per contract in both cases. This compares favorably with the average A+B contract size of around $20 million. Although this is not a social welfare measure—since additional contractor costs are unobserved, and bid changes may be a poor proxy for reasons discussed earlier—it still suggests that the policy provided considerable value to taxpayers.

### *IV.D. Robustness*

Our methodology is subject to two reasonable critiques, both of which we address in the Online Appendix. The first is that the treatment effect may be nonlinear in the observables, and so imposing a linear or log-linear functional form as in the OLS regressions may introduce bias. To address this issue, we compute alternative estimates using nearest neighbor matching. We obtain very similar estimates, albeit with less precision.

A second potential problem is our assumption that there is no selection on unobservables. This is harder to address. We find it reassuring that the observable factors that influence assignment (such as traffic, lane closures, and the reopening penalty) are not statistically or economically significant in any of the regressions. This supports our argument that the factors determining assignment are orthogonal to the costs of contract acceleration. We have also explored a fuzzy regression discontinuity design approach, based on the discontinuous change in A+B assignment probability around the size thresholds. This approach requires only that the distribution of omitted factors is continuous around these thresholds. Again, the results are similar, though the estimated local increase in the winning bid (12.6%) is imprecisely estimated and sensitive to the choices of bandwidth and kernel. More details are available in the Online Appendix.

## V. Welfare Estimation and Counterfactual Analysis

Our analysis thus far suggests that the A+B contract design has worked well for Caltrans. But we haven't yet been able to say anything about welfare, since we don't know the underlying contractor costs of acceleration. To get at this, we will make some parametric assumptions and estimate a structural model for the supply of acceleration, which will enable us to examine counterfactual welfare under various scenarios. In particular, we will show that a cost-effective policy would be to scale back this program on the intensive margin (smaller time incentives) and scale it up on the extensive margin (more A+B contracts).

We must overcome two potentially important selection issues. The first is that participation in A+B contracts may not be random, and so we need to model entry into auctions. Second, the switch to a scoring auction favors quick contractors over cheap contractors, and we need to model the bidding process to examine how the shift in incentives affects the characteristics of winning bidders. We proceed sequentially, modeling the entry process and then the bidding process. Throughout, we allow firms to be observably heterogeneous on three dimensions: their distance from the contract site, whether they are in-state or out-of-state, and whether their capacity is over $50 million.[16]

### V.A. *Participation*

We estimate a simple reduced form logit model of bidder participation. The binary dependent variable is at the bidder-contract level, equal to 1 if the bidder bids on the contract and 0 otherwise. The results are shown in Table III. We find that that firms match on size and distance—bigger firms go after bigger contracts, and closer firms are more likely to enter. There is little evidence that A+B contracts attract more or less participation relative to the control group, with no joint significance in the A+B coefficients in columns (2)–(3). This does not rule out matching on time-varying unobservables, such as when firms with unobserved excess

16. Firm capacity is defined as the maximum backlog during the sample period, where "backlog" is the outstanding value of all contracts currently under way.

capacity are more likely to participate in A+B auctions. We try to control for this potential selection effect in later regressions by including the residual from this regression as a control. Nonetheless, the broad picture that emerges is that matching is essentially based on size and distance, rather than A+B status, and for that reason we use the full sample coefficients in column (5) for the rest of the structural estimation.

### V.B. *Estimating Acceleration Costs*

Now we turn to the heart of the structural analysis: analyzing bidding in A+B auctions. Let $\mathbf{x}$ be a vector of observed bidder and contract characteristics. Following the theory, bidders have latent time-varying private types $\theta$. Define the "base cost" $c_B(\mathbf{x}, \theta^B) \equiv c(d^E; \mathbf{x}, \theta^B)$ of completing the project on the original design engineer's schedule. Then letting the number of days accelerated be $\tilde{d} = d^E - d^B$, define the "acceleration cost" $c_A(\tilde{d}; \mathbf{x}, \theta^A) \equiv c(d^E - \tilde{d}; \mathbf{x}, \theta^A, \theta^B) - c_B(\mathbf{x}, \theta^B)$, subject to $c_A(0; \mathbf{x}, \theta^A) = 0$. $\theta^A$ and $\theta^B$ should be interpreted as the private cost components relating to acceleration and base costs, respectively.

The types $\theta = (\theta^A, \theta^B)$ are assumed to be independently and identically distributed across bidders and contracts (though they may be correlated). The assumption that types are independent across contracts for the same bidder is obviously strong. Our bidder observables—firm capacity, location, and distance—will allow for some persistence, but ultimately there's no getting around the fact that this is not a dynamic model. We return to this point in the discussion of the counterfactual results.

Given this setup, we would like to estimate the supply curve for acceleration, which is the marginal cost curve $c_A'(\tilde{d}; \mathbf{x}, \theta^A)$. Let bidders be indexed by $i$, let contracts be indexed by $j$. We adopt a log-linear specification of marginal costs:

$$c_{U,j} = c_A'(\widetilde{d_{ij}}; \mathbf{x}_{ij}, \xi_j, \theta_{ij}^A) = \widetilde{d_{ij}}^{\alpha} e^{\mathbf{x}_{ij}\beta + \xi_j + \theta_{ij}^A}, \tag{4}$$

where $\xi_j$ is a contract-specific unobservable. This specification is simple but flexible. It allows for linear marginal costs as a special case ($\alpha = 1$) but admits both concave and convex marginal costs. It also implies total acceleration costs of $\frac{1}{1+\alpha} c_{U,j} \widetilde{d_{ij}}$. Taking logs and rearranging terms, we obtain our main estimating equation:

$$\log \widetilde{d_{ij}} = \frac{1}{\alpha} \left( \log c_{U,j} - \mathbf{x}_{ij}\beta - \xi_j - \theta_{ij}^A \right). \tag{5}$$

TABLE III

FIRM PARTICIPATION IN CALTRANS CONTRACTS

| | Dummy for Participation | | | |
|---|---|---|---|---|
| | A+B Eligible Contracts | | | All Contracts |
| | (1) | (2) | (3) | (4) |
| Log Distance (miles) | −0.031*** | −0.031*** | −0.032*** | −0.012*** |
| | (0.001) | (0.001) | (0.002) | (0.000) |
| Firm Capacity > \$50M × Log Engineer's Estimate | 0.014*** | 0.014*** | 0.014*** | 0.006*** |
| | (0.002) | (0.002) | (0.002) | (0.000) |
| Firm Capacity > \$50M × Federal Contract | 0.001 | 0.001 | 0.001 | −0.003** |
| | (0.006) | (0.006) | (0.006) | (0.001) |
| Instate Contractor | −0.027*** | −0.027*** | −0.030*** | −0.015*** |
| | (0.008) | (0.008) | (0.010) | (0.002) |
| Firm Capacity > \$50M | −0.181*** | −0.180*** | −0.180*** | −0.068*** |
| | (0.034) | (0.034) | (0.034) | (0.005) |
| Federal Contract | −0.002 | −0.001 | −0.001 | 0.002** |
| | (0.006) | (0.006) | (0.006) | (0.001) |
| Log Engineer's Estimate | −0.006** | −0.006** | −0.006** | −0.002*** |
| | (0.002) | (0.002) | (0.002) | (0.000) |
| Log Engineer's Days | 0.000 | 0.000 | 0.000 | 0.000 |
| | (0.004) | (0.004) | (0.004) | (0.001) |
| Log Traffic | −0.006*** | −0.006*** | −0.006*** | −0.001*** |
| | (0.002) | (0.002) | (0.002) | (0.000) |
| AB Contract | | −0.002 | −0.012 | |
| | | (0.003) | (0.022) | |
| A+B × Firm Capacity > \$50M | | | 0.001 | |
| | | | (0.005) | |
| AB × Log Distance | | | 0.001 | |
| | | | (0.002) | |
| A+B × Instate Contractor | | | 0.007 | |
| | | | (0.018) | |
| District/Work/Year FE's | yes | yes | yes | yes |
| $N$ | 22005 | 22005 | 22005 | 215812 |
| Wald test of A+B coefficients ($p$-value) | | 0.623 | 0.979 | |

*Notes.* Average marginal effects from logit regressions of participation on covariates. A data point is a bidder-contract pair. Columns (1)–(3) are estimated only on contracts that are eligible for A+B assignment; column (4) is off of all contracts. "Firm capacity" is defined as the maximum backlog during the sample period, where "backlog" is the outstanding value of all contracts currently under way. District, year, and type of work fixed effects are included. Standard errors are robust and clustered by contract. Asterisks denote significance levels ($^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$). The $p$-value reported in the last row is of a Wald test of the joint significance of the A+B dummy and all interactions with it.

Written this way, this is a constant elasticity supply function, where $\widetilde{d_{ij}}$ plays the role of quantity, and $c_{U,j}$ the role of price. We estimate this by OLS.[17]

17. Supply elasticities are frequently estimated in the labor and public finance literature, and sometimes are sufficient for welfare analysis Chetty (2009). Here

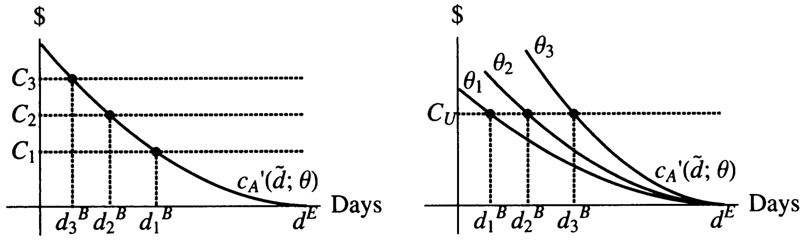


FIGURE III

Identification

The left panel shows the identification argument for a fixed type. Exogenous variation in the user costs from $C_1$ to $C_3$ causes the firm to bid different days, $d_1^B$ to $d_3^B$. The marked points can be plotted, and with sufficient variation, the entire marginal acceleration cost curve can be traced out. In the right panel, we show how differences in the days bid for a fixed user cost allows us to measure how much heterogeneity there is across firms.

*Identification.* Before estimation it is useful to think through the identification of the model. The argument is sketched in Figure III. To start, suppose that there were no type variation at all, so that there was a single acceleration supply curve $c_A'(\tilde{d};\theta)$ to identify. Then since contractors equate their marginal costs with the user cost, variation in user costs would induce contractors to bid different days. By matching the user cost with the days bid, as shown in the left panel of the figure, we can trace out the supply curve. This is entirely analogous to identifying supply from exogenous price or tax variation in other contexts. We also need to identity how much heterogeneity in types there is. This comes from looking at the variation in days bid for a given user cost, as in the right panel of Figure III.

Where is the exogenous variation in usercosts coming from? In our data, it is mainly coming from policy variation across districts. As we said earlier, district 4 user costs are essentially set by formula, based on the size and length of contract, type of work, and home engineer's office expenses.[18] So conditional on observables, user costs covary with the project engineer's office expenses, which are plausibly orthogonal to the contractor's acceleration costs. By

this is only partially true. Estimating the acceleration supply elasticity suffices for welfare analysis of the existing program. But a counterfactual change in time incentives also changes the distribution of winning types, and more modeling is required to address this.

18. In the Online Appendix, we show the formula predicts user costs very well.

contrast, in other districts the user costs are set equal to the district's estimates of the social cost of delay, which depend on the details of the construction plans, traffic patterns, and lane closures. Our identifying assumption here is that the difference between the actual user cost and the expected user cost conditional on our other observables (which include traffic and the maximum fraction of lane closures) is uncorrelated with the error term $\xi_j + \theta^A_{ij}$. This assumption is harder to evaluate; perhaps contracts that cause surprisingly long delays to commuters are also hard to accelerate. This would introduce bias in our estimates. Helpfully, a large part of the identifying variation comes from the fact that conditional on the same observables, district 4 sets lower user costs than the other districts—and this policy variation is exogenous.

*Estimation Results.* The results of the regressions are reported in Table IV. The first column has a basic set of contract-level controls, and the next three columns successively add firm-specific covariates, fixed effects, and the residual from the participation model in column (5) of Table III. The coefficient on log user cost is the elasticity of acceleration supply with respect to user cost. This elasticity is significantly different from 0 in all specifications, but small in magnitude, indicating inelastic supply. From Equation 5, the coefficient also has a structural interpretation as $\frac{1}{\alpha}$, implying $\alpha$ roughly equal to 3.5, and thus convex marginal costs of acceleration. This is consistent with what we know about the construction process: small reductions in time can be achieved at the same scale by cutting out contingency time, but larger reductions require genuine acceleration and operation at an inefficient scale.

The other coefficients have the expected signs. Longer contracts get more acceleration, whereas higher estimated cost contracts get less. This is consistent with a story in which contractors are constrained in how much work they can do each day, and so when there's more work each day (higher cost or fewer days) they offer to accelerate less. Big firms and firms closer to the contract site offer speedier construction, as one would expect. Finally, the coefficient on the participation residual is statistically insignificant and negative. This goes against matching on unobservables: if this were important, one would expect "unlikely entrants" to be better at contract acceleration, but this doesn't appear to be the case.

TABLE IV
INCENTIVES AND ACCELERATION IN A+B CONTRACTS

| | Log Days Accelerated | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Log Usercost | 0.262** | 0.314** | 0.275** | 0.275** |
| | (0.119) | (0.123) | (0.137) | (0.136) |
| Log Engineer's Days | 1.185*** | 1.275*** | 1.316*** | 1.312*** |
| | (0.211) | (0.213) | (0.228) | (0.228) |
| Log Engineer's Estimate | −0.168 | −0.249 | −0.310** | −0.314** |
| | (0.151) | (0.152) | (0.136) | (0.136) |
| Log Daily Traffic | 0.076 | 0.053 | 0.002 | 0.002 |
| | (0.093) | (0.095) | (0.068) | (0.067) |
| Plant Establishment Dummy | −0.340 | −0.352 | −0.295 | −0.291 |
| | (0.234) | (0.243) | (0.204) | (0.205) |
| Lane Closure Fraction | 0.795 | 0.855 | 0.840 | 0.836 |
| | (0.777) | (0.801) | (0.686) | (0.686) |
| Reopening Penalty | 0.045 | 0.034 | −0.239 | −0.235 |
| | (0.229) | (0.226) | (0.216) | (0.216) |
| Firm Capacity > $50M | | 0.307*** | 0.306*** | 0.250 |
| | | (0.112) | (0.105) | (0.202) |
| Instate Contractor | | −0.397* | −0.593*** | −0.565*** |
| | | (0.235) | (0.187) | (0.200) |
| Log Distance (miles) | | −0.088* | −0.051 | −0.028 |
| | | (0.052) | (0.042) | (0.084) |
| Participation Residual | | | | −0.286 |
| | | | | (0.725) |
| District/Work/Year FE's | no | no | yes | yes |
| $R^2$ | 0.296 | 0.313 | 0.407 | 0.408 |
| $N$ | 424 | 424 | 424 | 424 |

*Notes.* OLS Regressions of log days accelerated on covariates, where days accelerated is engineer's days less days bid."Firm capacity" is defined as the maximum backlog during the sample period, where "backlog" is the outstanding value of all contracts currently under way. "Participation Residual" is the residual from the participation regression of column (5) of Table III. District, year, and type of work fixed effects are included where indicated. Standard errors are robust and clustered by contract. Asterisks denote significance levels (*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$).

*The Type Distribution.* Up to now, we have been able to remain agnostic as to the distributions of $\xi_j$ and $\theta^A_{ij}$. But for simulation purposes, we need to be able to draw contract shocks and individual-specific types. This requires deconvolution of the error term $\xi_j + \theta^A_{ij}$. Given our limited data, it does not make sense to take the fully nonparametric approach of Li and Vuong (1998). Instead, we assume that both $\xi_j$ and $\theta^A_{ij}$ are normally distributed, i.i.d. across contracts and bidders, and independent of each other, with $\xi_j \sim N(0, \sigma^2_\xi)$ and $\theta^A_{ij} \sim N(0, \sigma^2_\theta)$. The deconvolution process is relatively straightforward: we estimate $\sigma_\theta^2$ from the variance of differences in residuals within contracts, and then back out $\sigma_\xi^2$ as the difference between the overall variance in residuals and our estimate of $\sigma_\theta^2$. Our estimated results imply that bidder heterogeneity accounts for more of the variance than contract heterogeneity.

### V.C. *Estimating the Bid Function*

To complete our analysis, we need a model of the "A part" or dollar bid submitted by bidders in A+B auctions. This will enable us to work out who wins the counterfactual auctions. Also, under some assumptions about markups, we will be able to bound the difference between the base cost of the cheapest contractor and the winning contractor (where those disagree), and therefore say something about how much the selection of fast contractors costs Caltrans. From the theory, bids are equal to cost plus a markup term that depends on the distribution of opposing scores:

$$b_{ij} = c_A(\widetilde{d_{ij}}; \mathbf{x}_{ij}, \xi_j, \theta_{ij}^A) + c_B(\mathbf{x}_{ij}, \xi_j, \theta_{ij}^B) + \text{markup}(\mathbf{x}_{ij}, \xi_j, \theta_{ij}^A, \theta_{ij}^B). \quad (6)$$

In principle, with enough data and a few more assumptions, one could recover the latent distribution of $\theta_{ij}^B$ given our estimated $\theta_{ij}^A$ and the first-order condition for bidding (Guerre, Perrigne, and Vuong 2000). But doing this convincingly would take us far afield. So instead, we specify a flexible reduced form for the ratio of bids to engineer's estimate:

$$\frac{b_{ij}}{c_{E,j}} = \alpha_j + \mathbf{x}_{ij}\beta + \gamma \frac{c_{U,j}}{c_{E,j}} \widetilde{d_{ij}} + \lambda \widehat{\theta}_{ij}^A + \varepsilon_{ij}^B, \quad (7)$$

where $\varepsilon_{ij}^B \sim N(0, \sigma_B^2)$. The specification is motivated by the theory. $\alpha_j$ is a contract fixed effect, capturing the average base cost. The term $\mathbf{x}_{ij}\beta$ controls for bidder-specific observables, while $\gamma \frac{c_{U,j}}{c_{E,j}} \widetilde{d_{ij}}$ accounts for the increase in bids due to acceleration. We would expect $\gamma$ to be positive. Finally, the term $\lambda \widehat{\theta}_{ij}^A$ is intended to account for any correlation between $\theta_{ij}^A$ and $\theta_{ij}^B$. Nonetheless this is just a reduced form, and one should not attach structural interpretations to any of these coefficients.[19]

We estimate this by OLS. The results are shown in Table V. Looking at the final column, we see that firms that are farther

19. We have tried more flexible specifications with squares and interactions, but these don't improve fit.

TABLE V
DOLLAR BIDS IN A+B AUCTIONS

| | Dollar Bid / Engineer's Estimate | | |
|---|---|---|---|
| Firm Capacity > $50M | −0.023* | −0.027** | −0.011 |
| | (0.013) | (0.012) | (0.018) |
| Instate Contractor | 0.109** | 0.116** | 0.109** |
| | (0.049) | (0.053) | (0.053) |
| Distance / Engest | 1886.732*** | 1865.765*** | 1557.196** |
| | (614.577) | (626.744) | (684.435) |
| Usercost × Days saved / Engest | −0.270 | 0.085 | 0.097 |
| | (0.241) | (0.202) | (0.199) |
| Bid Residual | | −0.038*** | −0.039*** |
| | | (0.014) | (0.014) |
| Entry Residual | | | 0.089 |
| | | | (0.064) |
| Contract FE's | yes | yes | yes |
| $N$ | 423 | 423 | 423 |

*Notes.* OLS Regressions of dollar bid/engineer's estimate on covariates, in A+B auctions. "Days saved" is the difference between the engineer's days and the days bid. Bid residual is the residual from the regression in column (4) of Table IV. "Engest" is the engineer's estimate. Entry Residual is the residual from the participation regression of column (4) of Table III. Contract fixed effects are included throughout. Standard errors are robust and clustered by contract. Significance levels are denoted by asterisks ($^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$).

from the job site bid higher amounts. Firms that submit a lower B-score relative to the engineer's estimate also bid more, as expected. The most interesting coefficient is the one on the bid residual $\widehat{\theta}^A$, which is negative and highly significant. This implies that the firms that offer to be surprisingly quick (conditional on the observables) are also likely to bid less. This may be because there is some fixed input, such as capacity, that creates a positive correlation between acceleration and base costs.[20]

From a big-picture perspective, this positive correlation makes A+B auctions more attractive. One might have thought that there was a big trade-off between fast and cheap contract completion, with some firms specializing in fast completion and others in cheap completion. In that case the use of A+B contracts would sharply raise base costs relative to the standard design, by favoring the fast but expensive contractors, and dealing with the commuter externality may not actually yield much of a welfare gain. What these regressions suggest is that the same kinds

20. We also estimate $\sigma_B^2$; the standard deviation in bids is about 7% of the engineer's estimate.

of firms participate in both kinds of contract—contrary to a specialization story—and that "fast" and "cheap" are positively correlated. This is good for welfare. A downside of this is that the best firms have increasing market power as the user cost increases, and their markups should reflect this. So although using A+B contracts appears to be particularly good for total welfare, it may raise procurement costs substantially.

### *V.D. Counterfactuals*

We are now able to model counterfactual changes and simulate their outcomes using our data set. We consider four A+B policies. In the first, we keep the same set of A+B contracts but set the user cost equal to the estimated social cost.[21] The second holds the number of A+B contracts approximately constant, but changes the mix, assigning A+B status only to contracts with a daily externality above $100,000 a day. The third is an expansion on both the extensive and intensive margins, with all contracts being let as A+B and user costs set equal to social cost. Finally, the last policy is a "budget policy" where all contracts are A+B but incentives are scaled back to 10% of the social cost. Because acceleration costs are convex, this last policy aims to get a lot of "bang per buck" by using A+B contracts frequently (to incentivize acceleration) but with small incentives (to keep costs low).

The simulation procedure is relatively straightforward: for each A+B auction, we draw entrants according to the participation model and simulate bids for those entrants using the acceleration and bid regressions. Repeating this process many times, we get average outcomes for that auction.[22] Throughout we hold the primitives constant: the distribution of types, bid and contract shocks, as well as the acceleration supply curve. We also assume that the entry process and (dollar) bid function are unaffected by the counterfactual policies. These assumptions are obviously strong, but at least on an auction-by-auction basis we are staying within the observed data: we have estimated bidding and participation in A+B auctions directly from observations of these auctions. Market-level or general equilibrium effects are ignored.

21. We are poorly identified outside of the support of the user costs. To avoid extrapolation, we bound the counterfactual user costs above so that the maximum B-score cannot exceed the engineer's estimate.

22. See the Online Appendix for more details on the simulation procedure.

*Model Fit.* A number of sample moments and their simulated counterparts are shown in Table VI. Fitting these moments is a fairly strong test of the estimated model as a whole, since we separately estimated a series of individual models for entry, acceleration, and bidding. If any of the models was misspecified, it should show up in the simulated moments.

Consider the first two columns, which compare a set of important sample and simulated moments under the observed A+B assignment. The participation model fits well, although it slightly over-predicts the distance of participating bidders and under-predicts the fraction of big firms on big contracts. The estimated acceleration is close to what we observe, and within the 95% confidence interval for all moments. Finally, the bidding model does a good job on predicting the difference between the winning and the cheapest bidder, although it slightly over-predicts how often the bidder who offers to complete quickest will win the auction. Overall the fit is good, especially since few of these moments were directly matched during the estimation procedure.

*Results.* Table VII shows the main counterfactual results, which break down the main welfare effects of A+B assignment. The first effect is "commuter gain," the product of days saved and social cost, where days saved is the difference between the number of days taken under the A+B policy (assuming on-time completion) and the standard policy (assuming completion in 92.5% of the engineer's days).[23] The second effect is increased acceleration costs for the winning contractor. The last effect is an increase in base costs: since the A+B auction awards contracts based on score, rather than lowest bid, the winning contractor may have higher base costs than a rival. In measuring this we face the problem that we see only bids, not the latent costs.

Without a full structural model of bidding, we are forced to make an assumption on markups to get at costs. Based on our earlier observations about the positive correlation between acceleration and base costs, we expect the winning bidder to have the most market power and charge the highest markups. As we show in the Online Appendix, if the winning bidder always has (weakly) the highest markup in the auction, we can construct an upper bound on the change in base costs, by taking the difference between the winning and cheapest bid in the A+B auction less the

23. The assumptions on completion time are estimated from the ex post data.

TABLE VI

SAMPLE AND SIMULATED MOMENTS OF THE STRUCTURAL MODEL

| | Data | | Simulations | | | |
|---|---|---|---|---|---|---|
| A+B Contracts<br>Usercost | Current<br>Current (1) | Current<br>Current (2) | Current<br>100% S.Cost (3) | S.Cost > $100K<br>100% S.Cost (4) | All<br>100% S.Cost (5) | All<br>10% S.Cost (6) |
| # AB Contracts | 77.00 | 77.00 | 77.00 | 83.00 | 662.00 | 662.00 |
| Avg. Usercost ($K) | 13.90 | 13.90 | 32.80 | 25.51 | 15.33 | 2.96 |
| # Bidders | 4.84 | 4.86 | 4.86 | 4.86 | 4.86 | 4.86 |
| # Bidders if AB | 5.51 | 5.63 | 5.63 | 5.52 | 4.86 | 4.86 |
| Avg. bidder distance | 111.40 | 121.94 | 121.94 | 121.94 | 121.94 | 121.94 |
| Big firms | 0.33 | 0.31 | 0.31 | 0.31 | 0.31 | 0.31 |
| Big firms if >$10M | 0.66 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 |
| Engdays - days bid | 100.78 | 98.93 | 116.61 | 79.24 | 51.89 | 34.92 |
| (if AB) | – | (86.7,109.7) | (94.1,142.2) | (60.2,93.6) | (40.8,60.6) | (22.7,49.2) |
| Engdays - days bid | 55.74 | 50.56 | 60.95 | 44.76 | 28.23 | 19.96 |
| (if AB & engdays <250) | – | (42.9,58.2) | (48.9,75.1) | (30.3,52.7) | (20.1,33.4) | (12.4,28.1) |
| Engdays - days bid | 142.45 | 143.67 | 168.10 | 213.09 | 183.33 | 118.02 |
| (if AB & engdays >250) | – | (125.3,162.1) | (133.6,208.4) | (166.3,268.4) | (144.0,226.3) | (75.3,164.7) |
| Engdays - win days bid | 125.36 | 131.27 | 159.62 | 107.52 | 68.63 | 43.34 |
| (if AB) | – | (117.2,144.3) | (133.8,176.8) | (87.3,117.9) | (57.5,76.9) | (28.0,58.9) |
| Engdays - win days bid | 68.57 | 65.33 | 80.77 | 57.03 | 35.13 | 23.88 |
| (if AB & engdays <250) | – | (57.0,75.5) | (69.3,89.9) | (39.3,64.0) | (27.2,39.8) | (14.9,32.5) |

TABLE VI
(CONTINUED)

| | Data | | Simulations | | | |
|---|---|---|---|---|---|---|
| A+B Contracts | Current | Current | Current | S.Cost > $100K | All | All |
| Usercost | Current (1) | Current (2) | 100% S.Cost (3) | 100% S.Cost (4) | 100% S.Cost (5) | 10% S.Cost (6) |
| Engdays - win days bid | 177.89 | 192.28 | 232.56 | 303.55 | 254.75 | 151.44 |
| (if AB & engdays >250) | – | (170.5,219.6) | (192.7,262.1) | (245.2,336.6) | (206.2,294.4) | (95.5,202.4) |
| Pr(Win) if quickest | 0.45 | 0.53 | 0.69 | 0.77 | 0.63 | 0.48 |
| (if AB) | – | (0.50,0.59) | (0.64,0.75) | (0.69,0.87) | (0.57,0.72) | (0.44,0.55) |
| Winning - Lowest Bid ($M) | 0.16 | 0.14 | 0.44 | 0.35 | 0.14 | 0.01 |
| (if AB) | – | (0.08,0.18) | (0.12,0.65) | (0.07,0.57) | (0.04,0.21) | (0.01,0.01) |

*Notes.* Simulation results. The first column is the observed data; the second column is simulated moments under the observed A+B policy (i.e., same A+B contracts, same user costs); the third through sixth columns are counterfactuals. In column (3), we maintain the observed A+B assignment but the user costs are set equal to the estimated social cost; in column (4), all contracts with social cost above $100,000 a day are assigned A+B status and user cost is set equal to the social cost; in column (5) all contracts are A+B, with user cost equal to social cost; and in column (6), all are A+B, but the user cost is only 10% of the social cost. "S. Cost" is the estimated daily social cost. "Big Firms" is the mean fraction of firms with capacity over $50M participating in the auction; "Big Firms if >$10M" is the same object averaged only over contracts with engineer's estimate greater than $10M. "Pr(Win) if quickest" is the mean probability that the firm offering to do the job quickest wins the auction. "Winning - Lowest Bid" is the difference between the winning and lowest bid in the auction, which can be positive in A+B auctions. 95% confidence intervals are given in parentheses, and are generated by bootstrapping the regressions in Tables IV and V, by taking the 2.5th and 97.5th percentiles of the simulated results based on the bootstrapped coefficients. Confidence intervals are not reported for participation moments, since the participation model was not bootstrapped.

TABLE VII

COUNTERFACTUAL WELFARE ESTIMATES UNDER ALTERNATIVE A+B ASSIGNMENT POLICIES

| A+B Contracts<br>Usercost | Current<br>Current (1) | Current<br>100% S.Cost (2) | S.Cost > $100K<br>100% S.Cost (3) | All<br>100% S.Cost (4) | All<br>10% S.Cost (5) |
|---|---|---|---|---|---|
| Days Bid / Engdays (%) | 68.81 | 62.83 | 51.84 | 62.02 | 73.79 |
| | (65.54,72.67) | (55.89,69.01) | (43.81,66.82) | (54.26,73.38) | (62.35,85.37) |
| Mean Commuter Gain ($M) | 4.02 | 5.39 | 9.30 | 2.26 | 1.61 |
| | (3.51,4.49) | (3.97,7.12) | (6.45,11.29) | (1.72,2.77) | (1.12,1.96) |
| Mean Acc. Cost ($M) | 0.383 | 0.907 | 0.694 | 0.299 | 0.038 |
| | (0.052,0.781) | (0.113,1.777) | (0.088,1.428) | (0.037,0.599) | (0.006,0.063) |
| Change in Base Cost ($M) | 0.253 | 0.779 | 0.648 | 0.248 | 0.025 |
| | (0.152,0.350) | (0.379,1.105) | (0.296,0.916) | (0.126,0.340) | (0.015,0.031) |
| Mean Net Gain ($M) | 3.38 | 3.70 | 7.96 | 1.71 | 1.55 |
| | (2.77,3.93) | (3.01,4.41) | (5.39,9.67) | (1.28,2.08) | (1.03,1.90) |
| Total Cost Increase ($M) | 49.02 | 129.85 | 111.37 | 362.14 | 41.91 |
| | (16.39,81.98) | (44.46,215.94) | (36.48,179.01) | (125.72,597.55) | (13.19,60.06) |
| Total Net Gain ($M) | 260.16 | 285.16 | 660.36 | 1135.31 | 1027.12 |
| | (213.67,302.51) | (231.71,339.95) | (447.73,803.00) | (847.55,1374.37) | (684.29,1259.63) |

*Notes.* Counterfactual welfare results under different policies. The first column is the observed data; the second column is simulated moments under the observed A+B policy (i.e., same A+B contracts, same user costs); the third through sixth columns are counterfactuals. In column (3), we maintain the observed A+B assignment but the user costs are set equal to the estimated social cost; in column (4), all contracts with social cost above $100,000 a day are assigned A+B status and user cost is set equal to the social cost; in column (5) all contracts are A+B, with user cost equal to social cost; and in column (6), all are A+B, but the user cost is only 10% of the social cost. "S. Cost" is the estimated daily social cost. "Commuter Gain" for any contract is calculated as the product of commuter welfare and the difference between the days bid and 92.5% of the engineer's days, since A+B contracts are completed on time and standard contracts are typically completed 7.5% early. "Acceleration Cost" is the estimated additional cost to the winning contractor of this accelerated construction schedule. "Change in Base Cost" is an upper bound on the change in the base cost of completing the project from selecting the highest scoring rather the bidder with the lowest base cost (under the assumption that the winning bidder employs (weakly) the highest markup). "Net Gain" is a lower bound on the welfare gain from A+B assignment. "Cost Increase" is the sum of acceleration costs and the change in base cost. In all cases, mean results are averaged across simulations and A+B contracts. Totals are obtained by summing the relevant statistics across all A+B contracts. 95% confidence intervals are given in parentheses, and are generated by bootstrapping the regressions in Tables IV and V, and taking the 2.5th and 97.5th percentiles of the simulated results based on the bootstrapped coefficients.

difference between the winning and maximum acceleration costs of any bidder in the auction. The markup assumption follows from the equilibrium first-order conditions for bidding under bidder symmetry, but need not under asymmetry—and in that sense our bound is an approximation. We report this statistic here allowing for bidder asymmetry, but show also in the Online Appendix that when the entire model is reestimated assuming symmetry, the results do not significantly change.

Our main conclusions come from the total net welfare gains in the last row.[24] There is very little difference in total welfare between the first two columns, implying that Caltrans has done well in assigning incentives. The biggest gains come from expansion of the program to include all contracts, as shown in the fourth and fifth column. Even when incentives are set at only 10% of the social cost, as in the budget policy, the social welfare gain is still over $1 billion. Remarkably, this is achieved with a lower estimated total cost increase than the current policy. Sensitivity analysis shows that these basic patterns are robust to specification, alternative assumptions about the supply elasticity, and lower social cost estimates.[25]

*Discussion.* As conceded earlier, we could be missing important dynamic and general equilibrium effects. In terms of dynamics, if types were perfectly persistent and capacity constrained, then an expansion of the A+B program might fare worse than we project, as the best types would be unable to participate on all these contracts. But it seems plausible that type is determined by something like capacity, which evolves, so as some firms get busy, others will be able to step in. The general equilibrium concern is that accelerating all contracts would cause input prices to rise. This is not necessarily right: if overall demand for highway construction contracts remains constant, long-run input demand will also stay constant. The question is whether contractors operating at bigger scale over shorter periods of time will lead to bottlenecks in input supply, and this seems far from clear.

The bottom line is that time incentives should be a part of every contract awarded by Caltrans. Moreover, a policy of small time incentives seems prudent. Our estimates suggest that a large part of the welfare gain can be achieved with small incentives.

24. Since the change in base cost is an upper bound, these are a lower bound on the net welfare gains.

25. See the Online Appendix for the sensitivity analysis.

In addition, such incentives are minimally distortionary, limiting the risk that firms might try to sacrifice quality for speed (though there is no evidence this currently occurs). Most important, this policy may be practical from a budgetary perspective.

## VI. Conclusion

Governments and firms spend large amounts of money on procurement. The traditional contracting approach specifies every dimension of the good to be procured (for example, quality and delivery time), and then relies on some competitive mechanism to award the procurement contract. In U.S. federal procurement, auctions are often used. This has the advantage of picking the cheapest contractor who can deliver the specified good, but in the absence of repeat contracting, leaves no incentive for that contractor to outperform and deliver a better than required good.

This is exemplified by the highway construction contracts in California that we have examined in this article. Standard contracts specify how many days the contractor may take for construction, but give them no incentive to finish early. Yet social welfare certainly depends on the time taken for construction, since construction work causes costly commuter delays. Scoring auctions such as the A+B design studied here allow for contracts to be awarded on multiple factors, such as money and time. This can enhance efficiency by providing incentives for accelerated contract completion.

We compared outcomes of A+B and standard contracts awarded by Caltrans between 2003 and 2008 to look for evidence of welfare gains. It is striking how much quicker the A+B contracts are completed. They take just 60% of the engineer's estimate, on average, versus 92.5% for standard contracts. The difference is still of the same order of magnitude after adding controls and taking steps to deal with selection. So it seems clear that contractors have the ability to accelerate construction beyond standard targets, and providing time incentives gets them to do so.

But one might wonder how much this costs. We estimate that for a typical A+B contract, procurement costs rise by 7.5% relative to a similar standard contract. This still looks like a good deal, as the gain to commuters from quicker completion is estimated to be around 30%. There also don't appear to be any hidden costs: there is no evidence of lower quality of work for the

A+B contracts. When we simulate counterfactual outcomes using a structural model of participation and bidding, we show that the *potential* welfare gains are even larger. By expanding the A+B program to include all contracts, and by providing small time incentives, a welfare gain of nearly $1 billion could be generated.

There are two main takeaways from the article. The first is that there can be large welfare gains from using scoring auctions to award contracts based on quality as well as price. This relies on there being asymmetric information between contractors and the procurer on the marginal costs of supplying quality (else one could contract on efficient supply), and on "quality" being both well defined and ex post verifiable. The second and perhaps more surprising conclusion is that incentives needn't be large or indeed optimal to have significant effects. Uncertainty about or difficulties in calculating the "right" level of incentives should not prevent the use of these auction designs altogether.

This setting is somewhat special in that reputational concerns are limited. An interesting question for future research is how important explicit scoring mechanisms are when suppliers already have an incentive to perform well to receive repeat business.

HARVARD UNIVERSITY AND NATIONAL BUREAU OF ECONOMIC RESEARCH
UNIVERSITY OF MINNESOTA AND NATIONAL BUREAU OF ECONOMIC RESEARCH

## REFERENCES

Arditi, David and C. Jotin Khisty, "Incentive/Disincentive Provisions in Highway Contracts," *Journal of Construction Engineering & Management*, 123 (1997), 302–307.

Asker, John and Estelle Cantillon, "Properties of Scoring Auctions," *RAND Journal of Economics*, 39 (2008), 69–85.

———, "Procurement When Price and Quality Matter," *RAND Journal of Economics*, 41 (2010), 1–34.

Athey, Susan and Jonathan Levin, "Information and Competition in U.S. Forest Service Timber Auctions," *Journal of Political Economy*, 109 (2001), 375–417.

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

Bajari, Patrick, Stephanie Houghton and Steven Tadelis, "Bidding for Incomplete Contracts: An Empirical Analysis of Adaptation Costs," Working Paper, University of Minnesota (2007).

Branco, Fernando, "The Design of Multidimensional Auctions," *RAND Journal of Economics*, 28 (1997), 63–81.

Che, Yeon-Koo, "Design Competition through Multidimensional Auctions," *RAND Journal of Economics*, 24 (1993), 668–680.

Chetty, Raj, "Sufficient Statistics for Welfare Analysis: A Bridge between Structural and Reduced-Form Methods," *Annual Review of Economics*, 1 (2009), 451–488.
Einav, Liran and Ignacio Esponda, "Endogenous Participation and Local Market Power in Highway Procurement," Working paper, NYU Stern and Stanford (2008).
Fick, Gary, Ells Tom Cackler, Steve Trost and Lee Vanzler, "Time-Related Incentive and Disincentive Provisions in Highway Construction Contracts," Technical Report 652, National Cooperative Highway Research Program, Washington, DC (2010).
Gil, Ricard and Justin Marion, "The Role of Repeated Interactions, Self-Enforcing Agreements and Relational [Sub]Contracting: Evidence from California Highway Procurement Auctions," Working Paper, University of Santa Cruz (2009).
Guerre, Emmanuel, Isabelle Perrigne and Quang Vuong, "Optimal Nonparametric Estimation of First-Price Auctions," *Econometrica*, 68 (2000), 525–574.
Herbsman, Zohar J., Wei Tong Chen, and William C. Epstein, "Time Is Money: Innovative Contracting Methods in Highway Construction," *Journal of Construction Engineering & Management*, 121 (1995), 273–281.
Hong, Han and Matthew Shum, "Increasing Competition and the Winner's Curse: Evidence from Procurement," *Review of Economic Studies*, 69 (2002), 871–898.
Jofre-Bonet, Mireia and Martin Pesendorfer, "Estimation of a Dynamic Auction Game," *Econometrica*, 71 (2003), 1443–1489.
Krasnokutskaya, Elena, "Identification and Estimation in Highway Procurement Auctions under Unobserved Auction Heterogeneity," *Review of Economic Studies, forthcoming.*
Krasnokutskaya, Elena and Katja Seim, "Bid Preference Programs and Participation in Highway Procurement Auctions," *American Economic Review, forthcoming.*
Laffont, Jean-Jacques and Jean Tirole, "Auctioning Incentive Contracts," *Journal of Political Economy*, 95 (1987), 921–937.
Lewis, Gregory and Patrick Bajari, "Incentives and Adaptation: Evidence from Highway Procurement in Minnesota," Working Paper, Harvard University (2010).
Li, Tong and Quang Vuong, "Nonparametric Estimation of the Measurement Error Model Using Multiple Indicators," *Journal of Multivariate Analysis*, 65 (1998), 135–165.
Li, Tong and Xiaoyong Zheng, "Entry and Competition Effects in First-Price Auctions: Theory and Evidence from Procurement Auctions," *Review of Economic Studies*, 76 (2009), 1397–1429.
Manelli, Alejandro and Daniel Vincent, "Optimal Procurement Mechanisms," *Econometrica*, 63 (1995), 591–620.
Marion, Justin, "Are Bid Preferences Benign? The Effect of Small Business Subsidies in Highway Procurement Auctions," *Journal of Public Economics*, 91 (2007), 1591–1624.
Pogash, Carol, "A Miracle-Worker Highway Man Rides the Bonus Train," *New York Times*, June 2, 2007.
Porter, Robert and Douglas Zona, "Detection of Bid Rigging in Procurement Auctions," *Journal of Political Economy*, 101 (1993), 518–538.
Silva, Dakshina G. De, Timothy Dunne, Anuruddha Kankanamge and Georgia Kosmopoulou, "The Impact of Public Information on Bidding in Highway Procurement Auctions," *European Economic Review*, 52 (2008), 150–181.
Strong, K., C. Tometich and N. Raadt, "Cost Effectiveness of Design-Build, Lane Rental, and A + B Contracting Techniques," in Mid-Continent Transportation Research Symposium Ames, IA (2005).
Weitzman, Martin L., "Prices vs. Quantities," *Review of Economic Studies*, 41 (1974), 477–491.