Bidding for Incompete Contracts

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Summary

When procurement contracts are incomplete, they are frequently changed after the contract is awarded to the lowest bidder. This results in a final cost that differs from the initial price, and may involve significant transaction costs due to renegotiation. We propose a stylized model of bidding for incomplete contracts and apply it to data from highway repair contracts. We estimate the magnitude of transaction costs and their impact using both reduced form and fully structural models. Our results suggest that transactions costs are a significant and important determinant of observed bids, and that bidders strategically respond to contractual incompleteness. Our findings point at disadvantages of the traditional bidding process that are a consequence of transaction costs from contract adaptations.

Keywords: Procurement, Construction

JEL Classification: D23, D82, H57, L14, L22, L74

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1 Introduction

Procurement of goods and services is commonly performed using auctions of one type or another, the benefits of which are well known and vigorously advocated. Namely, competitive bidding will result in low prices and sets rules that limit the influence of favoritism and political ties. When the good being procured is complex and hard to specify, it is often the case that alterations to the original design are needed after the contract is awarded and production begins. This may result in considerable discrepancies between the lowest winning bid and the actual costs that are incurred by the parties. A leading example is the "Big Dig" in Boston where 12,000 changes to more than 150 design and construction contracts have led to $1.6 billion in cost overruns, much of which can be traced back to unsatisfactory design and site conditions that differed from expectations.[1]

It is often argued that changes to an ongoing contract have an impact not only on the direct costs of production, but also impose significant transactions costs in the form of haggling, dispute resolution and opportunistic behavior (Williamson, 1985 Ch.1). In this paper we develop a model of bidding in the face of incomplete contract design, and provide evidence that bidders respond strategically to contractual incompleteness. More importantly, we present evidence suggesting that the resulting transaction costs are significant in highway improvement contracts awarded by the California Department of Transportation (Caltrans). We then offer some thoughts on how these significant inefficiencies may be reduced.

Highway improvement projects, like many projects in the construction industry, can involve a fair amount of uncertainty about the final good that will be produced (See, e.g., Bajari and Tadelis, 2001, and the references therein). This problem of contractual incompleteness and production uncertainty is common to other industries such as oil drilling (Corts and Singh, 2004), aerospace (Masten, 1984) and defense procurement (Crocker and Reynolds, 1993). That said, most of the existing theoretical and empirical literature on bidding for procurement contracts (with a few notable exceptions listed below) abstracts away from incompleteness and assumes that there is no discrepancy between the ex ante plans and specifications, and what is actually built ex post.

Our analysis begins by observing that highway improvement projects are often procured

[1] According to the Boston Globe, "About $1.1 billion of that can be traced back to deficiencies in the designs, records show: $357 million because contractors found different conditions than appeared on the designs, and $737 million for labor and materials costs associated with incomplete designs." Responsibility for these cost overruns is a subject of heated debate. See http://www.boston.com/news/specials/bechtel/part_1/

using *unit-price auctions*. These are tailored to situations where there is little uncertainty about *which* measurable inputs that are needed for production, but there may be significant uncertainty about *how much* of each input will be needed. Procurement starts with an engineering estimate of the quantities required for each input. Contractors then bid a per unit price for each input, and the contractor with the lowest estimated total bid, computed by multiplying the unit prices by the engineering estimated quantities, is the winner. Actual quantities will practically always differ, resulting in potentially significant gaps between the estimated bid and the actual ex post payment. The final payment may also differ due to a change in the scope of the project. This may be necessary, as in the Big Dig, when the original plans and specifications are inadequate to complete the job. Furthermore, the final payment may be altered because of deductions, which are penalties for delays in completing the project or inferior workmanship. In our data, for example, the final payment was up to fifty percent larger than the winning bid.

In Section 2 we then discuss how standard highway contracts work when the plans and specifications are changed. We pay particular attention to how compensation is adjusted when changes are required. We proceed to lay out a stylized model of competitive bidding in Section 3, which captures this form of contractual incompleteness. This allows us to study the contractors' bidding incentives, and suggests both reduced form and structural models that can be ten the at.e at we hae cli ha(C9)5s$(ffiH49M5i$(C9ffi5n$M)935f$(C9ffi5a$M)9R5r$actienboMM)9R
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that in the private sector, open competitive bidding for fixed price contracts is only infrequently used because it is perceived to create large and inefficient levels of transactions costs. We interpret our finding as further empirical evidence that transactions costs are one of the leading disadvantages of the traditional competitive bidding system.[2]

A closely related paper is Athey and Levin (2001), which demonstrates that bidders behave strategically when the estimated proportions of tree species on a forest timber contract differ from the actual proportions. Our paper is also related to a growing literature that uses structural estimation of auction models to infer underlying unobservables.[3] We follow in this tradition by using a similar two-step estimation approach, but with different first order conditions that incorporate the effect of anticipated changes on ex ante bidding behavior. Like others whom have studied bidding for highway procurement, we find that bidders are asymmetric and account for this in our empirical models. (See, e.g., Porter and Zona (1993), Hong and Shum (2002), Bajari and Ye (2003) and Krasnokutskaya and Seim (2004).)

This paper makes three contributions to the literature. First, our results suggest that for many procurement applications, the standard models of bidding are mis-specified because they do not account for contractual incompleteness and ex post anticipated changes. Payments from changes to the contract are substantial, and imply that an important part of a contractor's profit is often omitted in standard models. Thus, if the procurement contract is incomplete, and if contractors incorporate this in their bidding behavior, our analysis suggests that the most commonly used left hand side variable of estimated costs is incorrect, and furthermore, that important right hand side variables are omitted.

Second, our approach allows us to estimate contractors' private information and markups. Athey and Levin (2001) demonstrated that if bidders are better informed about the final quantities than the government agencies, bids will be strategically manipulated. However, their paper does not attempt to recover bidder markups. We estimate an *ex ante* markup and decompose it into markups over direct costs and over ex post changes in the contract due to incompleteness. Our results suggest that markups will be mis-measured, possibly severely, if we do not account for incompleteness.

Third, our paper contributes to the literature on transactions costs economics by gener-

[2] Corts and Singh (2004) and Chakravarty and MacLeod (2004) also consider the procurement process when the original contract is subject to ex post changes, but there focus is more in lines of contractual forms, similar to Bajari and Tadelis (2001).

[3] See for instance, Hortacsu (2002), Li, Perrigne, and Vuong (2002), Campo, Guerre, Perrigne and Vuong (2003), Pesendorfer and Jofre-Bonet (2003), Bajari and Ye (2003), Cantillion and Pesendorfer (2003), Hendricks, Pinkse and Porter (2003), Bajari and Hortacsu (2003).

ating estimates of transactions costs from contractual incompleteness. While transaction cost economics dates back to the arguments laid out by Williamson (1975, 1985), to the best of our knowledge there are no empirical estimates of the *dollar value* of these costs. As Pakes (2003) argues, one of the uses of structural estimation is to recover estimates of costs that are rarely, if ever, observed in the data. We demonstrate that a standard markup equation can be modified to yield an estimate of transactions costs, and offer a fully structural approach to the empirical analysis of transaction costs.

2 Competitive Bidding for Highway Contracts

As described in Hinze (1993) and Clough and Sears (1994), procurement for highway construction, as well as many other procurements in the public sector, is often done using competitive bidding on unit price contracts. For such contracts, civil engineers first prepare a list of items that describe the tasks and materials required for the job. For example, in the contracts we investigate, items include laying asphalt, installing new sidewalks, and striping the highway. For each work item, the engineers provide an estimate of the quantity that they anticipate contractors will need in order to complete the job. For example, they might estimate 25,000 tons of asphalt, 10,000 square yards of sidewalk and 50 rumble strips. The itemized list is publicly advertised along with a detailed set of plans and specifications that describe exactly how the project is to be constructed.

A contractor that wishes to bid on the project will propose per unit prices for each of the work items on the engineer's list. A contractor's bid is therefore a vector of unit prices that specifies his price for each contract item. Figure 1 shows the basic structure of a completed bid, which must be sealed and submitted prior to a set bid date. When the bids are opened, the contract is awarded to the contractor with the lowest estimated total bid, defined as the sum of the estimated individual line item bids (calculated by multiplying the estimated quantities of each item by the unit prices in the bid).[4]

[4] There are situations in which the Department of Transportation (DOT) can choose not to award the contract to the low bidder. The low bid can be rejected if the bidder is not appropriately bonded or have a sufficient amount of work awarded to disadvantaged business enterprises as subcontractors. Also, the DOT may reject bids judged to be highly unbalanced and therefore irregular.

Item	Description	Estimated Quantity	Per Unit Bid	Estimated Item Bid
1.	asphalt (tons)	25,000	25.00	625,000.00
2.	sidewalk (square yds)	10,000	9.00	90,000.00
3.	rumble strip	50	5.00	250.00
		Final Bid:		$715,250.00

Figure 1: Unit Price Contract–An Example.

As a rule of thumb, final quantities are never equal to estimated quantities. For example, the engineers might estimate that it will take 25,000 tons of asphalt to resurface the stretch of highway but 26,752 tons are actually used. The difference, in fact, may be substantial if there are unexpected conditions or if work has to be redone or eliminated. As a result, final payments are almost never equal to the original bid. The determination of the final payment can be rather complicated, and in many cases is not the sum of actual item costs given the unit price bid. Caltrans' *Standard Specifications* and its *Construction Manual* discuss the determination of the final payment at length. To a first approximation, there are three primary reasons for modifying the payments away from the vector product of unit prices and actual quantities.

First, if the difference between the estimated and actual quantities is small, then the contractor will indeed be paid the unit price times the actual quantity used. If the deviation is larger, however, or if it is thought to be due to negligence by one party, both sides will renegotiate an *adjustment of compensation*.[5] This adjustment is the difference between the vector product of the unit prices and actual quantities and the amount that the contractor is actually paid for the contract items. Consider the contract in Figure 1. If the asphalt ran over by 10,000 tons, instead of just a few thousand, Caltrans would hesitate to pay $250,000 more than they had anticipated. The parties might negotiate an adjustment of -$20,000 to bring the total bill down. In our data, these adjustments are always recorded as a lump sum reduction or increase, but one might also think of them as a way for parties to adjust the implied unit price on a particular item.

Second, in addition to changes in the estimated quantities, there may be a *change in scope* of the project. For instance, the original scope of the project might be to resurface 2 miles of highway, but the engineers and contractor might discover that the subsurface is not stable and that certain sections need to be excavated and have gravel added. In most cases, the contractor

[5]In the particular case of highway construstion procured by Caltrans, this type of adjustment is called for if the actual quantity of an item varies from the engineer's estimate by 25 percent. See the discussion of changes in the *Standard Specifications* and the *Construction Manual*.

and Caltrans will negotiate a *change order* that amends the scope of the contract as well as the final payment. If negotiations break down, this may lead to arbitration or a lawsuit. Payments from changes in scope are recorded as *extra work* in our data.

Finally, the payment may be altered because of *deductions* imposed by Caltrans. If work is not completed on time or if it fails to meet standard specifications then Caltrans may deduct liquidated damages, which are often a source of disputes. The contractor may argue that the source of the delay is poor planning or inadequate specifications provided by Caltrans, while Caltrans might argue that the contractor's negligence is the source of the problem. The final deductions imposed may be the outcome of heated negotiations or even lawsuits and arbitrations between contractors and Caltrans.

It is widely believed in the industry that some contractors attempt to strategically manipulate their bids in anticipation of changes to the payment. Contractors may strategically read the plans and specifications to forecast the likelihood and magnitude of changes to the contract. For instance, consider the example of Figure 1, in which the total bid is $715,250. Suppose that after reading the plans and specifications, the contractor expects asphalt to overrun by 5,000 tons and sidewalk to under-run by 3,000 square feet. If he changes his bid on sidewalk to $5.00 and his bid on asphalt to $26.60 then his total bid will be unchanged. However, this will increase the contractors' expected total payment to $833,750.00 ($26.6 \times 30,000 + 5 \times 7000 + 5 \times 50$) compared to $813,750.00 when bids of $25.00 and $9.00 are entered. A profit maximizing contractor can therefore increase his total payment *without increasing his total bid* and thus will not lower his probability of winning the job. A bid is referred to as *unbalanced* if it has unusually high unit prices on items that are expected to overrun and unusually low unit prices on items expected to under-run.

Athey and Levin (2001) note that the optimal strategy for a risk neutral contractor is to submit a bid that has zero unit prices for some items that are overestimated, and put all the actual costs on items that are underestimated. This strategy will maximize the expected ex-post payment while keeping the total bid unaltered. In the data, however, while zero unit price bids have been observed, they are very uncommon. Athey and Levin argue that risk aversion is one reason why this might occur, which in the absence of ex post changes seems like a plausible explanation for bidding behavior. After speaking with some highway contractors and reading industry sources we believe that for construction contracts other incentives are more important. Namely, Caltrans is not required to accept the low bid if it is deemed to be irregular (see Sweet (1994) for an in depth discussion of irregular bids). A highly unbalanced bid is a sufficient condition for a bid to be deemed irregular. As a result, a bid with a zero unit price is very likely, if not certain to be rejected. In our data, 5 percent of the contracts are not awarded to the low bidder, and according to industry sources the mostly likely reason is unbalanced bids.

Also, the *Standard Specifications* and the *Construction Manual* indicate that unit prices on items that overrun by more than 25 percent are open to renegotiation. In these negotiations, CalTrans engineers will attempt to estimate a fair market value for a particular unit price based on bids submitted in previous auctions and other data sources. Also, CalTrans may insist on renegotiating unit prices even if the overrun is less than 25 percent if the unit prices differ markedly from estimates. This suggests that there are additional limitations on the benefits of submitting a highly unbalanced bid.

In addition to unbalancing or skewing their unit bid prices, there are other ways in which contractors may bid strategically when faced with incomplete contracts. For example, they might notice inadequacies in the plans and specifications and forecast a certain amount of extra work that will have to be negotiated through change orders. Even if the negotiations for such change in scopes become arduous or heated (as is often the case), it is still possible for the contractor to earn some ex post rents. Suppose that the contractor expects a twenty percent markup on renegotiated work. If the change order leads to a $500,000.00 increase in compensation, this will lead to a $100,000.00 increase in ex post profits on the part of the contractor. This additional expected profit makes winning the project more attractive and hence increases the contractor's incentive to lower his bid. Similarly, contractors may know that the monitoring engineer assigned by Caltrans is particularly harsh on deductions, making the project less attractive and resulting in higher ex ante bids.

3 Bidding for Incompletely Specified Contracts

In this section we use the factual descriptions above to develop a simple variant of a standard private values auction model that will be the basis for our reduced form and structural empirical models.

3.1 Basic Setup

A project is characterized by a list of tasks, $t = 1, ..., T$ and a vector of estimated quantities for each task q_t^e. The actual quantities used to complete the project are q_t^a. We will let $\mathbf{q}^e = (q_1^e, ..., q_T^e)$ and $\mathbf{q}^a = (q_1^a, ..., q_T^a)$ denote the vectors of estimated and actual quantities.

Since the focus of our study is on the potential transaction costs from ex post changes and not on the rents that contractors receive due to their private information, we assume an extreme form of asymmetric information between the buyer and sellers. In particular, we assume that each contractor in the set of available bidders N has perfect information about the actual quantities $\mathbf{q}^a$ while the buyer does not. Since we will assume that contractors are risk neutral, this specification can be interpreted as contractors not having *exact* information about $\mathbf{q}^a$, but instead having symmetric uncertainty about the actual quantities, and therefore they have the same expectations over actual quantities. This interpretation is useful for the empirical analysis because it generates a source of noise that is not specific to the contractor's information or the observable project characteristics.

Despite the fact that contractors all share the same accurate information about $\mathbf{q}^a$, they differ in their private information about their own costs of production. Let c_t^i denote firm i's per unit cost to complete task t and let $\mathbf{c}^i = (c_1^i, ..., c_t^i)$ denote the vector of i's unit costs. The total cost to i for installing the vector of quantities $\mathbf{q}^a$ will be $\mathbf{c}^i \cdot \mathbf{q}^a$, the vector product of the costs and the actual quantities. These costs are known only to bidder i, but the distribution of $\mathbf{c}^i$ is common knowledge. This specification, together with the exact information that contractors have about $\mathbf{q}^a$, depicts a situation where contractors know exactly what needs to be done to meet the contract but they have private information about the costs of production (as in the most common type of procurement models).

Contractors bid by submitting a unit price vector $\mathbf{b}^i = (b_1^i, ..., b_T^i)$ where b_t^i is the unit price bid by contractor i on item t. Contractor i wins the auction and is awarded the contract if and only if $\mathbf{b}^i \cdot \mathbf{q}^e < \mathbf{b}^j \cdot \mathbf{q}^e$ for all $j \neq i$. That is, the contract is awarded to the lowest bidder, where the total bid is defined as the vector product of the contractor's unit price bids and the estimated quantities.

Let $R(\mathbf{b}^i)$ be the gross revenue that a contractor expects to receive when he wins with a bid of $\mathbf{b}^i$. If a risk neutral contractor has costs $\mathbf{c}^i$ then his expected profit from submitting a bid $\mathbf{b}^i$ is given by,

$$\pi_i(\mathbf{b}^i, \mathbf{c}^i) = \left(R(\mathbf{b}^i) - \mathbf{c}^i \cdot \mathbf{q}^a\right) \times \Pr\left\{\mathbf{b}^i \cdot \mathbf{q}^e < \mathbf{b}^j \cdot \mathbf{q}^e \text{ for all } j \neq i\right\}$$

where the interpretation is standard: the contractor receives the net payoff of revenue less *actual* production costs only in the event that all other bidders submit bids with higher *estimated* costs as calculated using the estimated quantities.

3.2 Revenues and Transaction Costs

If the only source of revenue were the vector product of the unit prices with the actual quantities, then revenues would equal $\sum_{t=1}^{T} b_t^i q_t^a$. As discussed in the previous section, however, there are three other components that affect the gross revenue of the project: adjustments, extra work, and deductions. Following our assumption of risk neutrality, and assuming that the contractors have rational expectations about the distribution of each component, we can introduce each of these three components as expected values, and include them additively into the contractors' profit function.[6] We denote the expected income (or loss) from adjustments as A, from extra work as X, and from deductions as D.

In the absence of transaction costs, the gross revenue would just be the sum

$$\sum_{t=1}^{T} b_t^i q_t^a + A + X + D.$$

However, in the presence of transaction costs such as haggling, dispute resolution, and renegotiation costs, every dollar earned has less than its full impact on revenues. These transaction costs can be generated by generated from several sources of inefficiency. One example is bargaining with asymmetric information when ex post changes and adjustments are needed, which was applied to procurement contracts in Bajari and Tadelis (2001). Another source could be wasteful investments in srengthening one's bargaining position, or other wasteful influence activities that cannot be avoided in equilibrium (see Milgrom, 1988).

In reality, transaction costs are likely to be a combination of all the frictions we mentioned above. We choose to be agnostic about the exact way in which transaction costs are imposed, and instead we take a first stab at measuring the role played by transaction costs in bidding for contracts using a reduced form addition to the standard model described above. We do this by introducing coefficients that will express the proportional dissipated surplus for each of the three revenue components from changes.

First, it is useful to distinguish between positive additions to ex post revenues and negative ones. By definition, any extra work adds compensation to the contractor while any deduction is an ex post loss incurred by the contractor. This implies that $X > 0$ and $D < 0$. The adjustments A, however, can be positive or negative, so we distinguish between positive adjustments,

[6] Another simplistic way of interpreting this is that contractors have perfect forsight of these components. We discuss this distinction in Section 5.

$A_+ > 0$, and negative ones, $A_- < 0$. We can write down the total ex post revenue as,

$$\sum_{t=1}^{T} b_t^i q_t^a + (1-\alpha_+)A_+ + (1+\alpha_-)A_- + (1-\gamma)X + (1+\delta)D. \qquad (1)$$

To interpret (1) first note that for positive ex post income, transaction costs will cause some fraction of the surplus to be dissipated. The positive coefficients α_+ and γ are a measure of these losses. For negative ex post income, transaction costs mean that the contractor will suffer a loss above and beyond the accounting loss imposed by the adjustments or deductions. The positive coefficients α_- and δ are a measure of these losses.

If there are no transaction costs involved, then all four coefficients would be equal to zero. Thus, these coefficients capture a particular linear reduced form of the transaction costs imposed by ex post changes. This specification may be incorrect if, say, transaction costs are not linear. Indeed, if one thinks about the stories of haggling and influence cost inefficiencies, then it is likely that as the stakes are higher, so will be the wasteful effort, maybe resulting in non-linear transaction costs. As a first step, however, this simple specification is useful in that the lack of transaction costs will be revealed by the data if the estimated coefficients are zero. If they are not, however, then this will indicate the presence of transaction costs, the exact form of which can then be measured with more scrutiny.

To complete the specification of profits, we add a component that captures the loss from submitting irregular bids that are highly skewed. Athey and Levin (2001) argue that risk aversion may be one reason for a loss from skewed bids. After speaking with some highway contractors and reading industry sources such as Bartholomew (1998), Clough and Sears (1994), Hinze (1993) and Sweet (1994), it seems that other incentives may be more important to curtail skewed bidding, and we discussed these in the previous section (the fact that CalTrans is highly likely to reject unbalanced bids). We impose a reduced form penalty that is increasing in the unbalancedness of the bid. In particular, we impose the following convenient functional form,

$$P(\mathbf{b}^i) = \varphi \sum_{t=1}^{T} \left(b_t^i - \bar{b}_t\right)^2 \left| \frac{q_t^e - q_t^a}{q_t^e} \right| .$$

To interpret this penalty, the term $\bar{b}_t$ represents the engineer's estimate for the unit cost of contract item t. The engineer staff at CalTrans has access to a variety of engineering cost estimates which are typically average bids for similar items submitted on previous jobs. This reduced form specification places convexity into the penalty function and makes zero bids on some items no longer optimal (consistent with Athey and Levin (2001), and with what we observe in our data). Also, it penalizes unbalancing bids for items where the percentage overruns are likely to be largest. While in principal we could consider a more flexible penalty function for unbalancing, the number of observations will limit the number of parameters we can include in this term. This, together with our objective of keeping the structure of the model as close to the standard literature as possible, is why we introduce this fairly parsimonious specification. This completes the specification of revenues as,

$$R(\mathbf{b}^i) = \sum_{t=1}^{T} b_t^i q_t^a + (1-\alpha_+)A_+ + (1+\alpha_-)A_- + (1-\gamma)X + (1+\delta)D - P(\mathbf{b}^i) \tag{2}$$

3.3 Equilibrium Bidding Behavior

Following standard auction theory, we will consider the Bayesian Nash Equilibrium of the static first-price sealed-bid auction as our solution concept. The probability that bidder i wins the auction with bid $\mathbf{b}^i$ depends on the distribution of the bids of each of the other $j \neq i$ contractors. Let $H_j(\cdot)$ be the cumulative distribution function of contractor j's total bid, $\mathbf{b}_j \cdot \mathbf{q}^e$. The probability that contractor i with a total bid of $\mathbf{b}^i \cdot \mathbf{q}^e$ bids more than contractor j is $H_j(\mathbf{b}^i \cdot \mathbf{q}^e)$. Thus, the probability that i wins the job with a total bid of $\mathbf{b}^i \cdot \mathbf{q}^e$ is $\prod_{j \neq i} \left(1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)\right)$, and the contractor's expected profit function is,

$$\pi_i(\mathbf{b}^i, \mathbf{c}^i) = \left(R(\mathbf{b}^i) - \mathbf{c}^i \cdot \mathbf{q}^a\right) \times \prod_{j \neq i} \left(1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)\right)$$

Given the cost vector $\mathbf{c}^i$, the contractor chooses unit prices to maximize expected utility. Substituting (2) for $R(\mathbf{b}^i)$, the partial derivative of profit with respect to the unit price b_t^i is:

$$\begin{aligned} \frac{\partial \pi_i}{\partial b_t^i} = \; & \left(q_t^a - 2\varphi\left(b_t^i - \overline{b}_t\right)\left|\frac{q_t^e - q_t^a}{q_t^e}\right|\right) \prod_{j \neq i} \left(1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)\right) \\ & + \left(\sum_t \left(b_t^i - c_t^i\right) q_t^a - \varphi \sum_t \left(b_t^i - \overline{b}_t\right)^2 \left|\frac{q_t^e - q_t^a}{q_t^e}\right| + (1-\alpha_+)A_+ + (1+\alpha_-)A_- + (1-\gamma)X + (1+\delta)D\right) \\ & \times \left(-\sum_{k \neq i} \frac{\partial H_k}{\partial b} q_t^e \prod_{j \neq i,k} \left(1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)\right)\right) \end{aligned}$$

Assume that $H_j(\cdot)$ is differentiable with density $h_j(\cdot)$, and assume that first order conditions are necessary and sufficient for describing optimal bidder behavior. Thus, if at the optimum $\frac{\partial \pi_i}{\partial b_t^i} = 0$ for all t, then we get t equations from the fact that for all $t \in \{1, ..., T\}$,

$$\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot \mathbf{q}^a = \frac{1}{q_t^e}\left(q_t^a - 2\varphi\left(b_t^i - \bar{b}_t\right)\left|\frac{q_t^e - q_t^a}{q_t^e}\right|\right)\left(\sum_{j \neq i} \frac{h_j(\mathbf{b}^i \cdot \mathbf{q}^e)}{1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)}\right)^{-1} + \varphi \sum_t \left(b_t^i - \bar{b}_t\right)^2 \left|\frac{q_t^e - q_t^a}{q_t^e}\right| - (1-\alpha_+)A_+ - (1+\alpha_-)A_- - (1-\gamma)X - (1+\delta)D \tag{3}$$

A Bayesian Nash Equilibrium is a collection of bid functions, $\mathbf{b}^i : \Re^{T+4} \to \Re^T$ that maps costs and expectations over changes to unit price bids, and simultaneously satisfied the system (3) for all bidders $i \in N$. We assume that such an equilibrium exists, and will therefore use (3) as the basis for our empirical analysis.

The first order condition (3) provides some insight into firm's optimal bidding strategies, and relates to the established literature of bidding without transaction costs and changes. When $\mathbf{q}^e = \mathbf{q}^a$, and when there are no anticipated changes, the first order condition reduces to:

$$\mathbf{b}^i \cdot \mathbf{q}^e - \mathbf{c}^i \cdot \mathbf{q}^e = q_t^e \left(\sum_{j \neq i} \frac{h_j(\mathbf{b}^i \cdot \mathbf{q}^e)}{1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)}\right)^{-1} \tag{4}$$

This is the first order condition to the standard first price, asymmetric auction model with private values. Thus, it is easy to see that our model is a simple variant of the standard models of bidding for procurement contracts (e.g., Porter and Zona (1993), Pesendorfer and Jofre-Bonet (2003) and others). That is, the markups should reflect the contractors cost advantage and informational rents as captured in the right hand side of (4). For example, in our application markups should depend on whether or not contractor i's competitor are close or far from the project, since this determines his relative advantage in the costs of hauling equipment and material. The markups should also depend on contractor i's uncertainty about his competitors costs

The innovation of the first order condition in (3) is the introduction of empirically measurable terms that are commonly ignored in previous studies. The first term, $-\varphi \sum_t \left(b_t^i - \bar{b}_t\right)^2 \left|\frac{q_t^e - q_t^a}{q_t^e}\right|$, reflects i's perceived penalty from unbalancing his bid so that his unit prices will not differ substantially from the norm (similar to the effects of risk aversion in Athey and Levin, 2001). The term $-(1-\alpha_+)A_+ - (1+\alpha_-)A_- - (1-\gamma)X - (1+\delta)D$ also influences the total ex post markup. To see this, suppose that the contractor expects a deduction of \$1,000. The first order condition suggest that the contractor will raise his bid by $(1+\delta)$ times \$1,000.00. Thus, the total costs of the deductions, as borne by the firm, are indirectly borne by the buyer, CalTrans.

Clearly, this model abstracts away from what are known to be fundamentally hard problems such as substituting the perfect foresight assumption on changes and actual quantities with a common values specification in which each bidder has signals of these variables. Despite these limitations, however, our first order conditions at a minimum generalize previous models, both theoretical and empirical, which implicitly impose the assumption that $\varphi = \alpha_+ = \alpha_- = \gamma = \delta = 0$. As we demonstrate shortly, this null hypothesis is strongly rejected by the data, and we will offer some evidence suggesting that transaction costs of ex post changes may indeed be the reason.

4 Data

We have constructed a data set of paving contracts procured by Caltrans during 1999. Our sample includes 162 projects with a value of \$369.2 million.[7] There were a total number of 679 bids submitted by 125 general contractors located primarily in California. Over half of the participating contractors, 70 firms, never won a contract during the period. In fact, only 7 firms participated in more than 10 percent of the auctions. To account for some of this asymmetry in size and experience, we will distinguish between top firms and "fringe" firms, where fringe firms are defined as those who each won less than 2 percent of the value of contracts awarded. We let $FRINGE_i$ be a dummy variable equal to one if firm i is a fringe firm. Tables 1 and 2 summarize the identities and market shares of the top firms, and Table 3 compares summary statistics of the top firms with those of the fringe.

For each contract, we have collected detailed information from the publicly available bid summaries and final payment forms that include the contract number, the bidding date, the location of the job site, the estimated working days required for completion, and other information about the nature of the job. They also contain the identities of the bidders and their itemized bids. Contracts are broken down into an average of 28 items, though some contracts have as many as 107 items. For each item, we have all bidders' unit prices, along with the

[7] The size of the market is defined as the value of the winning bids for the projects in our data set. As we discussed in section 2, this could be different than the final payments made to the contractors. We focus on those contracts for which asphalt constituted at least one third of the project's monetary value. We also exclude contracts that were not awarded to the lowest bidder since the lowest bid is then not included in our data. This is usually due to irregularities in the lowest submitted bid, bid relief granted to a contractor who claimed mistakes were made in his proposal, or other reasons for which the bidder was found to be ineligible. Such contracts represent about 5 percent of all paving projects under consideration.

estimated quantity of the item needed. Additionally, the bid summaries report the engineer's estimate of the projects cost. This measure, provided to potential bidders before proposals are submitted, is intended to represent the "fair and reasonable price" the government expects to pay for the work to be performed.[8] This estimate can be thought of as $\sum_t \bar{b}_t q_t^e$, the dot product of some "Blue Book" prices and the estimated quantities. While we have the total estimate, we do not have access to the individual $\bar{b}_t$. We do, however, have the 1999 Contract Item Cost Data Summary, published by Caltrans' Division of Office Engineer. These represent weighted averages of the low bidders' prices on many of the standard, recurring contract items.

From the final payment forms, we collect data on the actual quantities used for each item, from which we can construct specific measures of contract incompleteness and overrun. Additionally, the forms record the adjustments, extra work, and deductions that contribute to the total price of the contract. These correspond to the variables A, D and X introduced in the previous section.

To account for the role that geographic proximity plays in determining a firm's transportation cost, we construct a measure of distance of firm i to the job site of contract $j = 1, ..., J$ which we denote as $DIST_{i,j}$. The contract provides information about the location of the project, often as detailed as the cross streets at which highway construction begins and ends.[9] We combine this with the street address of each bidding firm, and record mileage and travel time as calculated by Mapquest's geographic search engine. Contractors may have multiple locations or branch offices; when this is the case, the location closest to the job site is used. For those contracts that cover multiple locations, we take the average of the distances and travel times to each location. Tables 4 and 5 summarize these calculated measures based on the ranking of bids. As expected, the contractors submitting the lowest bids also tend to have the shortest travel distances and times, reflecting their cost advantage.

It is clear that a firm's bidding behavior may be influenced by its production capacity and project backlog. In particular, firms that are working close to capacity may face a higher shadow price when considering an additional job. Following the methods used by Porter and Zona (1993), we construct a measure of backlog from the record of winning bids, bidding dates, and contract working days. We assume that work proceeds at a constant pace over the length of the contract, and define the variable $BACKLOG_{i,j}$ to be the remaining dollar value of

[8] See the "Plans, Specifications, and Estimates Guide," published by the Caltrans' Division of Office Engineer for additional information about the formation of this estimate.

[9] Where the location information is less precise, we use the city's centroid or a best estimate based on the post mile markers and highway names included on every contract.

contracts won but not yet completed at the time a new bid is submitted.[10] We then define $CAPACITY_i$ as the maximum backlog experienced for any day during the sample period, and the utilization rate $UTIL_{i,j}$ as the ratio of backlog to capacity. For those firms that never won a contract, the backlog, capacity, and utilization rate are all set to 0.

Discussions with industry participants have revealed that firms may take into account their competitors' positions when devising their own bids. For this reason, we will include measures of their closest rival's distance and utilization rate. Since we treat the distance from the construction site as a proxy of cost advantage, we define $RDIST_{i,j}$ as the minimum distance to the job site among bidders on project j, excluding firm i. Likewise, $RUTIL_{i,j}$ is the minimum utilization rate among bidders on project j, excluding firm i.

Summary statistics for the contracts and the bids are provided in Tables 6, 7, and 8. There is noticeable heterogeneity in the size of contracts awarded: the mean value of the winning bid is \$2.1 million with a standard deviation of \$2.4 million. The difference between the first and second lowest bids averages \$149,671, meaning that bidders leave some "money on the table." On average, the projects require just under three months to complete, and during this period, it is clear that several change orders are processed. The final price paid for the work exceeds the winning bid by an average of \$171,341.50, or about 6.4 percent of the estimate. Table 9 decomposes this discrepancy into its primary components and provides summary statistics that reveal their importance. A significant component can be attributed to overruns and under-runs on contract items. Not only are there deviations in quantity, but large deviations also induce a correction to the item's total price, captured by the value of adjustments. In our sample, the mean adjustment is \$109,382. Extra work negotiated through after-contract change orders, as well as deductions, contribute to the difference, averaging \$130,596 and -\$6,564 respectively. Taken together, the size of these ex-post changes suggests a certain degree of incompleteness in the original contracts.

[10]The measure of backlog was constructed using the entire set of asphalt concrete contracts, even though a few of these were excluded from the econometric analysis. Since we lack information from the previous year, the calculated backlog will underestimate the true activity of firms during the first few months of 1999; however, we believe the measure to be a sufficient proxy.

5 Empirical Analysis: Reduced Form Estimates

5.1 Standard Bid Regressions

We begin our analysis by performing some reduced form regressions in order to determine which covariates best explain the total bids. A regression of the total *estimated* bid, $\mathbf{b}^i \cdot \mathbf{q}^e$, on the engineer's estimate, $\overline{\mathbf{b}} \cdot \mathbf{q}^e$ yields an R^2 of 0.95 and a coefficient almost exactly equal to 1. This suggests that the engineering cost estimate is an unbiased predictor of the average total bid and can explain a large fraction of the variation of the bids in the data. This is consistent with previous papers that have studied this industry.

In Table 10, we regress the total *estimated* bid on various project characteristics. To correct for heteroskedasticity related to the overall size of the project, for each project j we divide each bid $\mathbf{b}^i \cdot \mathbf{q}^e$ by the engineer's estimate $\overline{\mathbf{b}} \cdot \mathbf{q}^e$. We denote this normalized variable as $NBID_{i,j}$. The explanatory variables include firm i's distance to the job site, its utilization rate, the minimum rival distance, the minimum rival utilization rate and N_j, the number of firms that submit a bid for contract j. In all of our regressions, distance is significant and has a positive sign as expected. In the first two columns, however, none of the other covariates are significant. The overall measure of goodness of fit is also not particularly high. In columns III and IV, we add project and firm fixed effects to the regression. The results suggest that both of these variables add considerably to goodness of fit, particularly project fixed effects. These effects capture characteristics of the job that are known to contractors but are unobserved in our data, such as the condition of the job site, the difficulty of the tasks, and economic conditions at the time of the contract.

While regressions such as those in Table 10 are common in the literature, equation (3) suggests that they are mis-specified. A more appropriate reduced form regression would use $\mathbf{b}^i \cdot \mathbf{q}^a$ as the dependent variable. In many cases, the distinction is not trivial. Because of misestimation on the part of Caltrans engineers, in our sample this value ranges from 44 percent less to 29 percent more than the estimated total bid, $\mathbf{b}^i \cdot \mathbf{q}^e$. Furthermore, in addition to including variables that shift i's cost and the costs of its competitors, the right hand side of the regression should include anticipated change orders, deductions, and expected quantity overruns. Recall from Section 4 and Table 9 that ex-post payment changes are sizeable. In our sample, the final payment typically differs from the winning bid by over 6 percent. These numbers suggest that by ignoring ex-post changes, the total payment to the contractor is often severely mis-measured in the literature.

5.2 Accounting for Changes and Transaction Costs

In Table 11, we present the results from the re-specified reduced form regression based on equation (3). The dependent variable, which we will refer to as $NACT_{i,j}$,is the *actual* payment $\mathbf{b}_i \cdot \mathbf{q}^a$ divided by a project estimate. Again, we wish to correct for heteroskedasticity related to the project's size, and since we are using variables that relate to individual items' quantities and prices, we would like to use a measure that is computed from these individual items. As mentioned in Section 4, we only have access to the engineer's aggregate estimate, while external cost estimates from the Contract Cost Data Book are not available for all items.

To circumvent this problem, we derive an estimate for $\bar{b}_t$ for each item t by using the mean of the unit prices bid in all the contracts that appear in our data, and then take the vector product of our derived $\overline{\mathbf{b}}$ and the estimated quantities $\mathbf{q}^e$ to construct our project estimate. This resulted in a total estimate that had an R^2 of 0.76 when regressed on the estimates we received from the CalTrans cost data book. Our method of averaging submitted bids to construct engineering estimates is similar to how they are constructed by professional estimating companies.

As columns V and VI demonstrate, when we only include the firm's and its competitors' cost shifters as covariates, the results appear to be similar to Table 10. A firm's own distance and whether or not it is a fringe firm appear to be the most important predictors of $NACT_{i,j}$. For a given contract, fringe firms tend to bid slightly more than non-fringe firms. Next, we include each of the ex post changes. We use $NDED_j$ and NEX_j to denote the values of deductions and extra work, both normalized by dividing through by the project estimate (these account for D and X in the theoretical model). We distinguish between positive adjustments and negative adjustments to compensation, $NPosAdj_j$ and $NNegAdj$, respectively (these account for A_+ and A_- in the model).

The results provide evidence that some form of frictions are imposed on the costs and revenues generated by ex post changes. For example, in column X of table 11, the coefficient on $NDED_j$ is -5.32 which implies for our model that $\delta = 4.32$. This suggest that if contractors expect an extra dollar of deduction, they will raise their bid by \$4.32 above and beyond the expected loss of \$1. This increase is a way for them to compensate for the expected loss, be it from costly haggling and bargaining or other frictions associated with changes. As we discussed in Section 3, if contractors were risk neutral and there were no transactions costs, the coefficient on deductions should be -1. The fact that the coefficient is -5.32 is consistent with there being \$4.32 of indirect costs for every dollar of deductions. For the 162 jobs that we study, this implies that deductions add \$4,593,924.00 to the final price paid by the State.

On the job with a -\$198,000.00 deduction (the largest in our sample), this implies an increased cost to the state of over \$850,000.00.

A similar interpretation may be given to the coefficient of -3 on negative adjustments, $NNegAdj_j$. When engineers underestimate the quantity of an item required to complete the job, the State will often negotiate a negative adjustment with a contractor who has bid that item at a high per unit price. Our regression results suggest that these negotiations carry with them a \$2.00 transaction cost for every dollar in corrections. If bidders anticipate high downward adjustments of this sort, they tend to raise their bids, not only to recoup the expected loss, but also to recover the transactions cost they must expend while haggling over price changes.

If there were no transactions costs and if contractors were risk-neutral, we would expect to find coefficients on positive adjustments equal to -1, implying that firms lower their bids by \$1 when they expect to receive an additional \$1 for work that has already been completed. The coefficient of 2.09 implies that firms actually tend to *raise* their bids when they expect this additional profit. One interpretation of this is that firms expect to spend \$3.09 in transactions costs for every dollar they obtain in adjustment.

The interpretation of the coefficient on extra work is a bit more complicated because in addition to transactions costs from negotiating change orders, firms must also account for the direct costs of performing the new work. In our conversations with industry participants, contractors suggested that a margin of 10 to 20 percent on change orders was a reasonable number for most firms in the industry. That is, for every \$1 of extra work awarded, the firm makes 10 to 20 cents of profit. Again, if there were no transactions costs and if contractors were risk-neutral, we would expect firms to lower their bids by 10 to 20 cents, keeping ex post profit unchanged. Our results suggests that firms instead tend to *raise* their bids by as much as \$1.67, which is consistent with there being some transactions costs in the magnitude of at least \$2.67 (more, taking the markup into account) for every dolar of extra work.

It is important to note that in reality, contractors do not know the exact deductions, adjustments, or extra work payments with certainty, but they may be able to forecast them. If contractors are risk neutral and do not have private information about deductions (so that the expectations of deductions are common among contractors), then the logic from Euler equation estimation suggests that we should still be able to use the coefficient on these payments to find an estimate of the implied transaction costs. The error term would now be interpreted as capturing the difference between the expected and actual change in payment.[11]

[11] That is, if contractors have correct (rational) expectations k^e for a change variable $\widetilde{k}$, then the correct

We now turn to estimate the penalty from skewing bids. To account for expected quantity changes, we include two alternative measures that serve as proxies. PCT_j is the average of the percent quantity overruns on each item t in project j. Although this measure reflects upon the civil engineers' errors in estimation, it does not preserve the relative importance of contract items. A 10 percent overrun on a small item like milepost markers is quite different than a 10 percent overrun on a major item like asphalt concrete. To account for this we constructed another measure, $NOverrun_j$, which is defined as the sum of the dollar overrun on individual items, divided by the project estimate. This dollar overrun is computed by multiplying the difference in the actual and estimated quantity by the item cost estimate reported in the Contract Cost Data Book. Since not all contract items are contained in the data book, $NOverrun_j$ should be thought of as a partial overrun due to quantity changes in the more standard items.

Finally, we can show that, like in Athey and Levin (2001), when contractors expect overruns they will actively skew their bids and their total payments will increase. The coefficient on the partial dollar overrun on standard contract items, $NOverrun_j$, is positive and significant. This is consistent with contractors giving skewed bids to increase their total payment without changing their probability of winning the job. In Table 12, we investigate the incentives to skew bids further by running a regression of item per-unit prices on the percent by which that particular item overran. The left hand side variable is the unit price divided by an engineer's estimate of the unit price.[12] When we allow for heteroskedasticity within an item code (by allowing for fixed or random effects), the coefficient on percent overrun is 0.049 and significant. That is, if a contractor expected a ten percent overrun on some item, he would shade his bid up by approximately one half of one percent, a very modest, but fairly significant coefficient.

regression is to regress bids on k^e. Assuming that the noise around k^e is orthogonal to the expectation, then using the actual change k we can rewrite the regression on $k+(k^e-k)$ where the difference between the expected and actual values is part of the orthogonal residual. Then, the coefficient on the actual value k is an unbiased estimate for the coefficient on k^e.

[12] We were able to obtain engineers estimates for a large fraction of the contract items used in our data. However, since they were not available for all items, we used the methods described earlier and took the mean of the unit prices bid in all of the contracts in our data as an alternative estimate. This had an R^2 of 0.76 when regressed on the estimates we received from the CalTrans web site. This construction allowed us to run the skewing regressions for all observations in our sample.

5.3 Risk Aversion: An Inconsistent Alternative

Arguably, the expected amount of an increase in compensation may not result in a one-to-one change of bids even in the absence of transaction costs. For example, if the expected extra work on a project is \$130,500 (which is the mean in our sample) then a risk averse contractor will lower his bid by less than this amount, which would correspond to a value of $\gamma > 0$ (or $(1-\gamma) < 1$), and this may be an alternative explanation for our coefficients.

This story, however, is impossible to justify with any reasonable preferences over risk. If we think of extra work as a lottery with positive support (recall that extra work is voluntarily negotiated with the contractor) then the most dissipation risk aversion could impose via a risk premium is to have such a lottery worth zero (worse-case preferences). Let $\gamma = \gamma_r + \gamma_{TC}$ to capture both risk and transaction costs. This argument implies an upper bound on how much of the coefficient γ can be explained by risk aversion, which we can write as $\gamma_r \leq 1$. This in turn implies a lower bound on transaction costs above an beyond any possible risk premium, $\gamma_{TC} \geq 1.67$ which means that for every expected dollar of extra work, at least \$1.67 is wasted through transaction costs.

The same argument holds for the estimate of α_+, which results in a lower bound of \$2.09 in transaction costs for every dollar of positive adjustments. However, a more careful analysis should treat adjustments as a lottery with positive and negative outcomes. To account for this, consider the transaction costs we estimate for all adjustments, which from the estimates of α_+ and α_- are in the order of \$2 to \$3 of waste for every dollar of change. This is in contrast to the transaction costs on deductions, where the estimate of δ is \$4.32. If these frictions were accounted for by risk aversion alone, then the higher premium on deductions would imply that the risk on deductions is higher. From table 9, however, it is easy to see that the lottery of adjustments is more risky than that from deductions, which is inconsistent with this simple risk story.

6 Structural Estimation

In this section, we propose a method for structurally estimating the model discussed in section 3. The estimation approach builds on Elyakime, Laffont, Loisel and Vuong (1994) and Guerre, Perrigne and Vuong (2000). In a first stage, the probability distribution of the bids is estimated. Next, we recover an estimate of φ, the coefficient on the penalty from skewing a bid. Finally, we estimate contractors' markups over project costs. Our results will allow us to decompose $\mathbf{b}_i \cdot \mathbf{q}^a$ into three terms. The first is the markup over costs due to market power and the contractors' private information. The second term involves how profits change as a function of deductions, extra work and adjustments. The third is the influence of the skewed bidding penalty. Knowledge of the relative importance of these three terms will allow us to better understand the observed bids and assess opportunities for improving the efficiency of the procurement mechanism.

6.1 Estimating Bid Distributions.

We begin by describing the "nitty-gritty" details of the estimator. The reduced form regressions of the last section can be used to generate the estimates for the change coefficients $\alpha_+ = 3.09$, $\alpha_- = 2.00$, $\gamma = 2.67$, and $\delta = 4.32$. In order to evaluate the empirical analogue of equation (3), we need to estimate $\left(\sum_{j \neq i} \frac{h_j(\mathbf{b}^i \cdot \mathbf{q}^e)}{1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)}\right)^{-1}$ as well as the coefficient φ. We consider each of these two steps in turn.

Much of the previous literature is concerned with nonparametric estimation of h_i and H_i. However, given that we have a rich set of covariates and a limited number of observations, a fully nonparametric approach is obviously not appropriate because of the curse of dimensionality. For this reason we use a more parsimonious specification that allows for some flexibility. Since the distribution of $\mathbf{b}_i \cdot \mathbf{q}^e$ determines the probability of winning, we begin by first running a regression similar to those in Table 10. The regression we run is

$$\frac{\mathbf{b}_i \cdot \mathbf{q}^e}{\overline{\mathbf{b}} \cdot \mathbf{q}^e} = x'_{i,j}\beta + \varepsilon_{i,j}$$

where as before the dependent variable is the normalized estimated bid, and the covariates $x_{i,j}$ include the firm's distance, whether or not it is a fringe firm, and an auction fixed effect. Let $\widehat{\beta}$ denote the estimated value of β and let $\widehat{\varepsilon}_{i,j}$ denote the fitted residual. We will assume that the residuals to this regression are iid with distribution $G(\cdot)$. The iid assumption would be satisfied if costs had a multiplicative structure which we describe in detail in the next subsection. Under these assumptions, we observe that

$$\begin{aligned} H_i(b) &\equiv \Pr\left(\frac{\mathbf{b}_i \cdot \mathbf{q}^e}{\overline{\mathbf{b}} \cdot \mathbf{q}^e} \leq \frac{b}{\overline{\mathbf{b}} \cdot \mathbf{q}^e}\right) \\ &= \Pr\left(x_{i,j}\beta + \varepsilon_{i,j} \leq \frac{b}{\overline{\mathbf{b}} \cdot \mathbf{q}^e}\right) \equiv G\left(\frac{b}{\overline{\mathbf{b}} \cdot \mathbf{q}^e} - x_{i,j}\beta\right) . \end{aligned} \tag{5}$$

That is, the distribution of the residuals, $\varepsilon_{i,j}$ can be used to derive the distribution of the observed bids. We estimate G using the distribution of the fitted residuals $\widehat{\varepsilon}_{i,j}$, and then recover an estimate of $H_i(b)$ by substituting in this distribution in place of G. An estimate of $h_i(b)$ can be formed using similar logic. We note that both $H_i(b)$ and $h_i(b)$ will be estimated quite precisely because there are 672 bids in our auction. Given the estimates $\widehat{H}_i$ and $\widehat{h}_i$ we generate an estimate $\left(\sum_{j\neq i} \frac{\widehat{h}_j(\mathbf{b}_i \cdot \mathbf{q}^e)}{1-\widehat{H}_j(\mathbf{b}_i \cdot \mathbf{q}^e)}\right)^{-1}$.

6.2 Estimating φ.

Next, we turn to the problem of estimating φ. Our approach will be similar to the identification of risk preferences described in Campo, Guerre, Perrigne and Vuong (2003). Assume that the distribution of private costs satisfies the following linear structure:

$$\mathbf{c}_i \cdot \mathbf{q}^a \equiv \widetilde{c}_i \overline{\mathbf{b}} \cdot \mathbf{q}^a. \tag{6}$$

That is, *actual* total costs can be represented as an independent, scalar random variable $\widetilde{c}_i$, times the engineering estimate $\overline{\mathbf{b}} \cdot \mathbf{q}^a$. We will assume that fringe firms may have a different distribution of $\widetilde{c}_i$ than non-fringe firms, but that within each of these two classes of firms the distributions are iid. Let $\widetilde{c}_i^f$ denote the cost random variable for a fringe firm i (we will suppress the additional notation for non-fringe firms). This assumption seems reasonable since the fringe dummy variable was the most important bidder specific covariate in our reduced form regressions. The other bidder specific covariates, while significant, did not contribute much to the overall goodness of fit. The assumption in (6) is similar to the multiplicative structure used in Krasnokutskaya (2004) and the location-scale models considered in Hong and Shum (2001) and Bajari and Hortacsu (2003). A similar assumption is also implicit in Hendricks, Pinkse and Porter (2001) where the lots are normalized by tract size.

By substituting (6) into (3) and dividing by $\overline{\mathbf{b}} \cdot \mathbf{q}^a$ we can write

$$\begin{aligned}
\widetilde{c}_i^f \;=\; & \left(\frac{1}{\overline{\mathbf{b}} \cdot \mathbf{q}^a}\right)\left(\mathbf{b}^i \cdot \mathbf{q}^a - \frac{q_t^a}{q_t^e}\left(\sum_{j\neq i} \frac{h_j(\mathbf{b}^i \cdot \mathbf{q}^e)}{1-H_j(\mathbf{b}^i \cdot \mathbf{q}^e)}\right)^{-1}\right) \\
& + \left(\frac{1}{\overline{\mathbf{b}} \cdot \mathbf{q}^a}\right)\left[(1-\alpha_+)A_+ + (1+\alpha_-)A_- + (1-\gamma)X + (1+\delta)D\right] \\
& - \varphi\left(\frac{1}{\overline{\mathbf{b}} \cdot \mathbf{q}^a}\right)\left[\sum_t \left(b_t^i - \bar{b}_t\right)^2 \left|\frac{q_t^e - q_t^a}{q_t^e}\right| - 2\left(b_t^i - \bar{b}_t\right)\left|\frac{q_t^e - q_t^a}{q_t^e}\right| \left(\sum_{j\neq i} \frac{h_j(\mathbf{b}^i \cdot \mathbf{q}^e)}{1-H_j(\mathbf{b}^i \cdot \mathbf{q}^e)}\right)^{-1}\right]
\end{aligned} \tag{7}$$

Notice from (7) that the right hand side can be decomposed into the first two lines that do not include φ, and the last that is linear in φ. We therefore can rewrite (7) as,

$$\widetilde{c}_i^f = f_1\left(\mathbf{b}^i, \overline{\mathbf{b}}, \mathbf{q}^a, \mathbf{q}^e\right) - \varphi f_2(\mathbf{b}^i, \overline{\mathbf{b}}, \mathbf{q}^a, \mathbf{q}^e) \tag{8}$$

where f_1 and f_2 are shorthand notation for the elements in (7). Since we have already generated estimates for the distribution and the coefficients on the revenues from changes, the only unknown on the right hand side of (8) is φ. Clearly, there is an analogous equation for the non-fringe firms that we suppress to save on space and excessive notation.

If $\varphi = 0$ and $\mathbf{q}^a = \mathbf{q}^e$, then we are in the standard setup where it is known that bid functions are strictly monotonic in costs. Therefore, our assumption in (6) would imply for the standard setting that there is a strictly monotonic relationship between $\widetilde{c}_i^f$ and the total bid divided by the estimate, $\frac{\mathbf{b}^i \cdot \mathbf{q}^a}{\overline{\mathbf{b}} \cdot \mathbf{q}^a}$. Despite the fact that we do not theoretically prove the monotonicity of bids in our auction, we will assume that bids are strictly monotonic in costs when $\varphi \neq 0$ and $\mathbf{q}^a \neq \mathbf{q}^e$. It would be surprising if this monotonicity would not hold in equilibrium, but a proof is beyond the scope of this paper. It is somewhat reassuring, however, given the fact that the contracts we study are open to all qualified bidders and are believed to have fairly tight margins. This suggests that the relationship between costs and bids cannot have a negative relationship for a large portion of the bid function since otherwise winning firms would incur losses.

Note that all of the terms in (8) except for φ and $\widetilde{c}_i^f$ can be evaluated given our previous estimates of the bid distributions and parameters multiplying changes, so we need to substitute out for $\widetilde{c}_i^f$ in order to identify φ. However, $\widetilde{c}_i^f$ is not observed for each firm individually, implying that we need to use the data to produce at least two independent equations for (8) that would allow us to cancel out the term associated with $\widetilde{c}_i^f$.

For example, we can create two sets of bids submitted by fringe firms, the first set including all fringe bids that were submitted in auctions with no more than three bidders, and the second set including all fringe bids that were submitted in auctions with more than three bidders. Then , from our assumption that $\widetilde{c}_i^f$ are iid, it must be the case that the median $\widetilde{c}_i^f$ is the same *for both* of these sets of fringe firm bids. From our monotonicity assumption, the median $\widetilde{c}_i^f$ can be identified from the median normalized bid, $\frac{\mathbf{b}^i \cdot \mathbf{q}^a}{\overline{\mathbf{b}} \cdot \mathbf{q}^a}$. This allows us to substitute for the median $\widetilde{c}_i^f$, and therefore generates two independent sources for the right hand side of (8) that must be equal. This in turn allows us to identify φ by equating the right hand sides for the median of both sets, which can be done since we can compute an estimate for both $f_1\left(\mathbf{b}^i, \overline{\mathbf{b}}, \mathbf{q}^a, \mathbf{q}^e\right)$ and $f_2(\mathbf{b}^i, \overline{\mathbf{b}}, \mathbf{q}^a, \mathbf{q}^e)$ for the median of each set of bids, using our previous stages.

Note that in addition to the median, similar restrictions must hold for *any* percentile of $\widetilde{c}_i^f$. Following Campo, Guerre, Perrigne and Vuong (2003), we estimate φ using restrictions from a large number of percentiles, not just the median. Let $\widetilde{c}_\rho^f$ denote the ρ^{th} percentile of $\widetilde{c}_i^f$. From (8), and using our monotonicity assumption, the percentile ρ of $\frac{\mathbf{b}^i \cdot \mathbf{q}^a}{\overline{\mathbf{b}} \cdot \mathbf{q}^a}$ identifies $\widetilde{c}_\rho^f$. Let $\mathbf{b}_\rho^{f(3)}$ denote the bid associated with the ρ percentile of the empirical distribution of $\frac{\mathbf{b}^i \cdot \mathbf{q}^a}{\overline{\mathbf{b}} \cdot \mathbf{q}^a}$ for the first set of bids. Let $\mathbf{b}_\rho^{f(4)}$ be the be the ρ percentile for the second set. Since the latent cost shock $\widetilde{c}_\rho^f$ is identical for $\mathbf{b}_\rho^{f(3)}$ and $\mathbf{b}_\rho^{f(4)}$, equation (8) implies that for every percentile ρ we choose,

$$f_1\left(\mathbf{b}_\rho^{f(3)}, \overline{\mathbf{b}}, \mathbf{q}^a, \mathbf{q}^e\right) - f_1\left(\mathbf{b}_\rho^{f(4)}, \overline{\mathbf{b}}, \mathbf{q}^a, \mathbf{q}^e\right) = \varphi\left(f_2(\mathbf{b}_\rho^{f(3)}, \overline{\mathbf{b}}, \mathbf{q}^a, \mathbf{q}^e) - f_2(\mathbf{b}_\rho^{f(4)}, \overline{\mathbf{b}}, \mathbf{q}^a, \mathbf{q}^e)\right) .$$

An analogous set of equations holds for the nonfringe firms.

Using the 25th through 75th percentiles, we estimate φ using a regression. The value of φ implied by this regression is 0.0007, which is statistically significant at the 6% level, but its quite small in monetary terms. It implies that if a contractor bids an item at \$10 over the estimated $\overline{b}_t$ and expects an overrun of 20%, then the implied penalty of doing this is only about one and a half cents.

As an additional robustness check on our results, we use a less elegant method that is inspired by facts from the industry. In particular, to estimate φ we assume that the fringe firms have a modest profit margin of 1-3 percent. This seems plausible given the fact that bidding is open to any qualified firm (free entry) and this margin is consistent with industry sources such as Park and Chapin (1992). This assumption allows us to identify φ because it becomes the only unknown parameter, and this specification led to a similar point estimate.

6.3 Completing the Structural Estimation

We are now in a position to estimate the implied markups for contractors in our dataset. We form our estimate, $\widehat{\mathbf{c}}^i \cdot \mathbf{q}^a$ of i's total cost for installing the actual quantities by evaluating the empirical analogue of (3):

$$\begin{aligned}\left(\mathbf{b}^i - \widehat{\mathbf{c}}^i\right) \cdot \mathbf{q}^a \quad &= \quad \frac{q_t^a - 2\widehat{\varphi}\left(b_t^i - \overline{b}_t\right)\left|\frac{q_t^a - q_t^e}{q_t^e}\right|}{q_t^e}\left(\sum_{j \neq i} \frac{\hat{h}_j(\mathbf{b}^i \cdot \mathbf{q}^e)}{1 - \hat{H}_j(\mathbf{b}^i \cdot \mathbf{q}^e)}\right)^{-1} \\ &+\widehat{\varphi}\sum_t \left(b_t^i - \overline{b}_t\right)^2 \left|\frac{q_t^a - q_t^e}{q_t^e}\right| - (1-\widehat{\alpha}_+)A_+ - (1+\widehat{\alpha}_-)A_- - (1-\widehat{\gamma})X - (1+\widehat{\delta})D\end{aligned}$$

Using our estimates of $\widehat{H}$, $\widehat{h}$, $\widehat{\varphi}$, $\widehat{\alpha}_+, \widehat{\alpha}_-, \widehat{\gamma}$ and $\widehat{\delta}$, it is possible to evaluate the right hand side of the above equation since all of the terms are either data or are parameters that we have described how to estimate.

We summarize the estimated markups in Tables 14a and 14b. Table 14a predicts markups for all contractors who submitted bids while Table 14b predicts the markups for winning firms only. The median markup over direct costs, $(\mathbf{b}^i - \mathbf{c}^i) \cdot \mathbf{q}^a$ is \$249,582 for all bids and \$465,989.00 for winning bids. The ratio of the markup to the estimate for the median job is 17.6% for all bids and 28.3% for winning bids. This markup may seem high, but it is not the only component of a firm's profit margin. Notice that the median contribution of adjustments, extra work, and deductions to net profit is -\$167,062 for all bids and -\$194,734 for the winning bids. Our results suggest that, because of transactions costs, firms lose money on *any* of these ex-post changes. Combined with a median skewing penalty of -\$93.06, the median net ex-post profit is estimated at \$50,555 for all bids, which is only 3.4% of the project estimate. For winning bids, this profit is 13%. We shall discuss the implications of these results for the design of the procurement mechanism in detail in the next subsection.

We compare these estimates with the markups predicted by traditional auction theory. Using our first stage estimates of $\hat{H}_j(\mathbf{b}_i \cdot \mathbf{q}^e)$ and $\hat{h}_j(\mathbf{b}_i \cdot \mathbf{q}^e)$ to calculate informational rents, we evaluate the empirical analogue of equation (4). These results, summarized in Table 15, look similar to the total markups reported in the last two columns of Table 14a and 14b. The median markup is \$215,306, or 12.5% of the estimate, among winning bidders.

By breaking down the total payment into its components, however, we gain a much more informative picture of the components of profits. The reason that our model generates the same order of markups for the true specification and the mis-specified regression lies in the source of profits. Since we assume that all the gains and losses from ex post change are bid away (there is symmetric information about these) then the only source of profits is the informational rents, which are the focus of the mis-specified estimation.

6.4 Some Limitations

Two possible limitations of our empirical framework are notable. First, our estimates of $\alpha_+, \alpha_-, \gamma$ and δ rely on exogeneity assumptions that could be objectionable. If changes to the compensation are correlated with omitted project attributes, then our estimates of these parameters will be biased. In our current work, we are constructing a more detailed data set that will allow us to sort the data by CalTrans districts. Since each district has partially autonomous management, we could reasonably expect differences in policies about changes and deductions across districts. We will attempt to use this as an instrument for changes in compensation. However, it is worth noting that our exogeneity assumptions are weaker than previous papers who have failed to control for changes to the contract. At a minimum, our results suggest that excluding changes to compensation is a questionable assumption.

Second, the statistical properties of our estimators need to be more formally developed. For instance, we have not yet accounted for the first stage error in our nonparametric density estimates. Also, we would like to estimate $\alpha_+, \alpha_-, \gamma$ and δ simultaneously with the other structural parameters if possible. However, it is worth noting that the density and cdf estimates are likely to be reasonably precise given that we use 672 observations in estimating these univariate distributions. Also, our results suggest that the current estimates of $\alpha_+, \alpha_-, \gamma$ and δ are reasonably precise.

7 Discussion

7.1 Lessons for Auction Design.

Our estimates imply some perhaps surprising lessons for the design of highway procurement auctions. The first is that the existing system seems to do a good job of limiting rents and promoting competition in that the *total* markup is fairly modest. The median bidder in our sample of 679 bids priced contract items so that, if he did win the contract, he could expect a profit of \$50,476, or 3.7% of the estimate. More interesting, though, is how firms make such a markup. Item-level reduced form regressions suggested that firms shade their bids upward very slightly when they expect a particular item to run over. Yet, there is another reason for them to raise their unit price and overall bids when contracts are incomplete. Because they expect to be penalized with deductions and downward adjustments in compensation, and because transactions costs erode more than any positive gains through change orders, they skew their bids upward to extract high rents on pre-specified contract items. Among winning bidders, the median value of this direct markup, $(\mathbf{b}_i - \mathbf{c}_i) \cdot \mathbf{q}^a$, is 28.3% of the project estimate.

Second, our estimates imply that transactions costs are important. Implied transactions costs on different types of final payment changes range from one and a half dollars to over four dollars for every dollar in change. When considering the amount of money awarded and deducted after the initial contract is signed, these costs are significant by any standard. Table 16 reports a lower and an upper bound for the transactions costs on each contract.[13] For

[13]These bounds are determined based on the possible margins that firms may collect on extra work through change orders. At best, firms receive \$1 in profit for every \$1 in extra cost (if they have no marginal costs to

half of the jobs in the sample, our estimates imply that firms spend as much on transactions costs as they earn in ex-post profit. In the worst case, transactions costs are over 58% of the estimate and six times as large as firm profits. Clearly there are inefficiencies in this system.

The state has a particular interest in trying to minimize transactions costs. An implication of equation (3) is that CalTrans is ultimately responsible for transactions costs on the project, as they are directly passed on from the bidders. Summing over all 162 contracts, the lower bound suggests that CalTrans spent $95.3 million on transactions costs alone in 1999. Even half of that number would be substantial. This point echoes the arguments in Bajari and Tadelis (2001) who show that the transactions costs from a procurement relationship with ex ante competition are all borne by the buyer.

Interestingly, one way to reduce these transaction costs may be to commit not to use deductions and adjustments as frequently. If contractors anticipate a lower frequency of these actions then they will not need to increase their bids to recoup the expected transaction costs from ex post changes to the contract. This resonates with Clough and Sears (1994) who argue that in recent years the level of adversarial relationships have increased dramatically, and have caused both contractors and buyers to resort to legal dispute resolution which is considered to be very inefficient and wasteful.

7.2 Concluding Remarks

Most of the existing literature on procurement is focused on designing a contract or auction that minimizes contractors informational rents while giving appropriate incentives to minimize moral hazard. Taken literally, in this industry, our analysis suggests that a perhaps more important problem is to limit transactions costs.

[**TO BE COMPLETED**]

8 References

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Table 1: Identities of Top 25 Firms

Firm ID	Firm Name	Market Share	Firm ID	Firm Name	Market Share
49	Granite Construction Co.	26.5%	11	Asphalt Construction Co. Inc.	1.9%
61	J. F. Shea Co. Inc.	9.1%	79	Mercer Fraser Co.	1.8%
65	Kiewit Pacific Co.	7.4%	87	Pavex Construction	1.8%
123	W Jaxon Baker Inc.	6.3%	14	B E C Construction Co.	1.7%
114	Teichert Construction	5.0%	6	All American Asphalt	1.5%
15	Baldwin Contracting Co. Inc.	3.6%	113	Sully Miller Contracting Co.	1.3%
85	Parnum Paving Inc.	2.9%	75	Matich Corporation	1.3%
50	Griffith Co.	2.9%	67	Lee's Paving Inc.	1.2%
45	George Reed Inc.	2.6%	81	Joint Venture: Nicholas Grant Corp.; CA Commercial Asphalt Corp.	1.1%
119	Union Asphalt Inc.	2.4%	106	Silvia Construction Inc.	1.1%
118	Tullis and Heller Inc.	2.4%	42	Gallagher and Burk Inc.	1.0%
1	A. J. Diani Construction Co. Inc.	2.2%	9	Arcadian Enterprises	1.0%
37	E. L. Yeager Construction Co. Inc.	2.0%		**TOTAL**	**92.0%**

Note: There were a total of 125 active bidders for asphalt concrete construction contracts in 1999. The firms listed above are the top 25 firms, ranked according to their market share, i.e. the share of total contract dollars awarded.

Table 2: Bidding Activities of Top 25 Firms

ID	No. of Wins	Total Bid for Contracts Awarded	Final Payments on Contracts Awarded	No. of Bids Entered	Participation Rate	Conditional on Bidding for a Contract			
						Average Bid	Average Engineer's Estimate	Average Distance (Miles)	Average Time to Job Site (Min)
49	29	87,523,837	97,769,187	104	64.2%	2,871,312	2,881,541	39.9	52.5
61	7	31,359,546	33,577,783	18	11.1%	4,133,522	3,818,085	92.7	112.4
65	3	24,717,559	27,353,158	12	7.4%	5,096,699	4,649,785	129.6	141.7
123	7	21,682,678	23,344,809	40	24.7%	2,845,090	2,861,163	152.3	182.3
114	9	16,597,563	18,590,133	27	16.7%	3,357,218	3,100,162	46.2	59.1
15	3	11,816,642	13,248,400	9	5.6%	4,008,788	3,572,369	47.5	68.4
85	7	9,214,762	10,570,965	11	6.8%	1,215,878	1,234,556	59.6	80.0
50	4	10,016,529	10,570,880	9	5.6%	3,283,336	3,973,770	33.8	38.7
45	5	8,629,916	9,584,688	10	6.2%	1,835,775	1,860,738	37.0	59.8
119	5	8,714,657	9,039,598	8	4.9%	2,318,096	2,744,050	36.6	39.2
118	2	8,564,856	9,006,218	5	3.1%	2,659,350	2,530,333	36.1	43.6
1	2	7,747,488	8,095,949	8	4.9%	1,737,470	1,979,491	43.2	49.9
37	1	7,365,873	7,406,310	4	2.5%	3,166,387	3,561,288	120.8	141.3
11	4	6,837,339	6,919,201	10	6.2%	2,680,773	3,149,691	26.1	36.5
79	6	6,374,092	6,692,809	12	7.4%	1,154,390	1,107,189	38.6	49.8
87	3	6,762,894	6,538,697	8	4.9%	1,814,911	1,678,723	19.0	23.4
14	5	5,796,134	6,195,209	8	4.9%	2,159,010	1,932,623	108.7	141.2
6	7	5,234,879	5,455,337	18	11.1%	651,432	780,152	26.5	30.5
113	4	4,817,976	4,909,594	17	10.5%	1,305,744	1,498,252	61.6	65.4
75	4	4,741,365	4,767,306	14	8.6%	722,983	826,532	53.4	62.7
67	2	3,838,054	4,490,483	4	2.5%	3,323,978	3,485,907	50.2	49.4
81	1	3,832,354	4,058,978	3	1.9%	3,094,679	3,232,977	28.9	37.3
106	1	3,837,510	4,002,519	6	3.7%	2,637,561	2,778,475	151.1	156.5
42	1	3,643,558	3,760,970	1	0.6%	3,643,558	3,849,385	5.5	9.5
9	2	3,726,541	3,735,670	10	6.2%	1,574,171	1,295,312	189.4	199.5

Table 3: Comparison Between Fringe Firms and Firms with Over 2% Market Share

	Fringe Firms	Non-Fringe Firms
Number of Firms	112	13
Number of Wins	78	84
Average Bid Submitted	$ 1,558,965	$ 2,963,763
Average Distance to Job Site (miles)	73.10	67.33
Average Travel Time to Job Site (minutes)	82.98	82.21
Average Capacity	$ 606,995	$ 10,271,010
Average Backlog at Time of Bid	$ 80,767	$ 3,023,101

Note: The above averages were calculated by first calculating the average for each bidder, then averaging these means over the fringe and non-fringe firms, respectively.

Table 4: Distance to Job Site (in miles)

	Mean	Std. Dev.	Min	Max		Mean	Std. Dev.	Min	Max

Table 8: Summary Statistics

	Obs	Mean	Std. Dev.	Min	Max
Across Contracts Under Consideration					
Winning Bid	162	2,107,795	2,352,809	84,600	13,995,193
Markup: (Winning Bid-Estimate)/Estimate	162	-0.0684	0.1679	-0.6166	0.7851
Normalized Bid: Winning Bid/Estimate	162	0.9316	0.1679	0.3834	1.7851
Second Lowest Bid	162	2,257,466	2,522,206	86,806	14,717,717
Money on the Table: Second Bid-First Bid	162	149,671	245,843	623	1,835,334
Normalized Money on the Table: (Second Bid-First Bid)/Estimate	162	0.0667	0.0601	0.0008	0.3476
Number of Bidders	162	4.19	1.75	2	10
Distance of the Winning Bidder	162	50.84	57.41	0.46	413.18
Travel Time of the Winning Bidder	162	63.16	65.19	1.00	411.00
Utilization Rate of the Winning Bidder	162	0.2160	0.2966	0.0000	0.9278
Distance of the Second Lowest Bidder	162	62.67	59.70	1.67	307.22
Travel Time of the Second Lowest Bidder	162	75.21	66.04	4.00	312.00
Utilization Rate of the Second Lowest Bidder	162	0.2511	0.3158	0.0000	0.9787
Across Bids Submitted					
Normalized Bid	679	1.0335	0.2093	0.3834	2.1686
Distance to Job Site	679	67.21	72.82	0.13	594.16
Travel Time to Job Site	679	79.73	77.88	0.00	580.00
Backlog at Time of Bid	679	2,941,189	6,279,424	0	26,261,586
Capacity	679	6,949,402	9,382,572	0	26,832,268
Utilization (Backlog/Capacity)	679	0.1913	0.2940	0.0000	0.9787
Minimal Distance Among Rivals	679	31.57	36.24	0.13	254.73
Minimal Travel Time Among Rivals	679	41.42	44.60	0.00	306.00
Minimal Utilization Among Rivals	679	0.0504	0.1465	0.0000	0.8466

Table 9: Importance of Ex-Post Changes

	Obs	Mean	Std. Dev.	Min	Max
Adjustments	162	109,381.60	202,771.60	-82,208.57	1,431,714
Adjustments / Estimate	162	0.0324	0.0605	-0.2273	0.4763
Extra Work	162	130,596.20	225,751.60	0	1,454,255
Extra Work / Estimate	162	0.0501	0.0667	0.0000	0.5541
Deductions	162	-6,563.62	26,570.64	-198,070	0
Deduction / Estimate	162	-0.0027	0.0114	-0.1084	0.0000
CCDB Overrun = (ActQ-EstQ)*CCDB price	162	-71,039.98	209,352.80	-1,108,056	319,502.70
CCDB Overrun / Estimate	162	-0.0307	0.0905	-0.4363	0.1672
Final Payment-Winning Bid	162	171,341.50	323,750.00	-252,973	2,447,146
(Final Payment-Winning Bid) / Estimate	162	0.0570	0.0957	-0.3062	0.4919

The CCDB Overrun is meant to reflect the dollar overrun due to quantities that were misestimated during the procurement process. It is only a partial measure of the quantity-related overrun, since some of the nonstandard contract items do not have a corresponding price estimate from the Contract Cost Data Book (CCDB). The project estimate, used to normalize this and the other measures, was generated by taking the dot product of the estimated quantities and average unit prices. This estimate was then scaled down so the normalized bid was approximately 1.

Table 10: Standard Bid Function Regressions

Variable	I.	II.	III.	IV.
$DIST_{i,t}$	0.0006511 (2.64)	0.0006365 (2.54)	0.0004015 (4.72)	0.0004002 (1.08)
$RDIST_{i,t}$	0.0021988 (4.86)	0.0013093 (2.75)	-0.0001939 (-0.73)	0.0006967 (1.16)
$UTIL_{i,t}$		-0.0934746 (-1.43)	0.0149143 (0.75)	-0.0175904 (-0.23)
$RUTIL_{i,t}$		0.0096606 (0.10)	-0.0069699 (-0.14)	0.0039824 (-0.04)
$FRINGE_i$		-0.0603591 (-1.59)		
N_t		-0.0458044 (-5.64)	0.0416089 (3.59)	-0.0386143 (-3.73)
Constant	0.9083513 (37.24)	1.216859 (22.03)	0.9727827 (62.51)	1.165682 (19.35)
Fixed Effects	No	No	Project	Firm
Adj R^2	0.0581	0.1051	0.9218	0.1874
Prob>F	0.0000	0.0000	0.0000	0.0016
Num. of Obs.	679	679	679	679

The dependent variable is the total bid divided by the scaled project estimate, where the total bid is the dot product of the estimated quantities and unit prices. Robust standard errors are used to compute t-Statistics, shown in parentheses.

Table 11: Bid Function Regressions Using Actual Quantities Instead of Estimates

Variable	V.	VI.	VII.	VIII.	IX.	X.
$DIST_{i,t}$	0.000748 (2.97)	0.000400 (4.65)	0.00086 (3.82)	0.000759 (3.50)	0.000430 (5.71)	0.000430 (5.71)
$RDIST_{i,t}$	0.001330 (2.88)	-0.000268 (-1.02)				
$UTIL_{i,t}$	-0.102415 (-1.56)	0.016433 (0.83)				
$RUTIL_{i,t}$	-0.010923 (-0.11)	0.000707 (0.01)				
$FRINGE_i$	-0.076572 (-2.00)	0.035127 (3.04)	-0.06891 (-2.13)	-0.050504 (-1.59)	0.030955 (2.76)	0.030955 (2.76)
N_t	-0.042714 (-5.22)					
$NDED_t$			-5.94076 (-5.59)	-5.281098 (-3.88)	-6.06276 (-11.28)	-5.320142 (-5.43)
NEX_t			1.43509 (6.17)	1.533031 (6.53)	1.59537 (7.37)	1.66513 (7.35)
$NPosAdj_t$			1.06951 (2.59)	1.951688 (5.55)	1.16975 (2.80)	2.09006 (6.03)
$NNegAdj_t$			-2.86679 (-6.63)	-2.893119 (-6.39)	-3.00611 (-13.95)	-3.00168 (-11.97)
PCT_t			-0.19143 (-2.99)		-0.20837 (-3.46)	
$NOverrun_t$				1.298034 (7.92)		1.38167 (9.00)
Constant	1.184674 (21.24)	0.957006 (61.41)	0.87306 (25.74)	0.869342 (26.21)	0.95220 (105.94)	0.95220 (105.94)
Fixed Effects	No	Project	No	No	Project	Project
Adj R^2	0.1052	0.9235	0.1453	0.1887	0.9237	0.9237
Prob>F	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Num. of Obs.	679	679	679	679	679	679

The dependent variable is the dot product of the unit price bids and the actual quantities, divided by the project estimate. Robust standard errors are used to compute t-Statistics, shown in parentheses. In the final two columns, the coefficients on NDED, NEX, NPosAdj, NNegAdj, PCT, and NOverrun are found by regressing the fixed effects onto these variables (which are constant within a project). NOverrun is a measure of the quantity-related overrun on standard contract items (those that have a CCDB unit price estimate). This overrun is calculated as the dot product of the CCDB prices (where available) and the difference between actual and estimated quantities.

Table 12: Skewed Bidding Regressions

Variable	OLS	Item Code Fixed Effects	Item Code Random Effects
Percent unit overrun	0.0426121 (1.83)	0.0489254 (7.08)	0.0426121 (6.69)
Constant	0.9962683 (139.00)	0.996162 (134.74)	0.9962683 (138.12)
Adj R^2	0.0023		
Prob>F	0.0679		
Nobs.	19071	19701	19701

The dependent variable is the unit price bid on each contract item, normalized by the average unit bid. The percent unit overrun is the percent difference between the actual and estimated quantities reported for that item.

Table 13: First-Stage Estimates Used in Structural Estimation

Variable	Estimate
α_+	3.09006
α_-	2.00168
γ	2.66513
δ	4.320142
φ	0.00070179

Table 14a: Markup Decomposition (All Bidders)

Percentile	Direct Markup	Direct <u>Markup</u> Estimate	Ex-Post Changes	Ex-Post <u>Changes</u> Estimate	Skewing Penalty	Skewing <u>Penalty</u> Estimate	Total Profit	Total <u>Profit</u> Estimate
	$(b_i\text{-}c_i)q^a$		$\alpha Adj + \gamma EX + \delta Ded$		$-\varphi \cdot \sum_\tau [(b_i\text{-}b)^2 \lvert\%Over_\tau\rvert]$		π	
10	25,337	3.9%	-1,177,991	-34.5%	-6,273.33	-0.648%	7,247	0.9%
20	44,641	6.3%	-630,120	-23.1%	-2,225.91	-0.092%	13,487	1.4%
30	79,898	8.9%	-394,249	-18.0%	-621.57	-0.028%	19,827	2.0%
40	147,401	13.2%	-250,324	-14.3%	-256.12	-0.014%	29,886	2.7%
50	249,582	17.6%	-167,062	-10.3%	-93.06	-0.007%	50,555	3.4%
60	374,643	21.1%	-76,471	-7.4%	-43.54	-0.003%	75,618	4.5%
70	585,032	25.7%	-37,249	-4.5%	-16.63	-0.001%	112,550	5.8%
80	912,445	38.0%	-19,512	-2.9%	-6.56	-0.001%	186,984	9.5%
90	1,630,686	57.9%	-8,897	-1.7%	-1.27	0.000%	346,888	17.9%

Table 14b: Ex-Post Profit Decomposition (All Winning Bidders)

Percentile	Direct Markup	Direct <u>Markup</u> Estimate	Ex-Post Changes	Ex-Post <u>Changes</u> Estimate	Skewing Penalty	Skewing <u>Penalty</u> Estimate	Total Profit	Total <u>Profit</u> Estimate
	$(b_i\text{-}c_i)q^a$		$\alpha Adj+\gamma EX +\delta Ded$		$-\varphi \cdot \sum_\tau [(b_i\text{-}b)^2 \lvert\%Over_\tau\rvert]$		π	
10	50,330	8.1%	-1,309,907	-39.0%	-6,242	-0.470%	28,268	4.3%
20	103,873	13.9%	-790,604	-25.1%	-1,850	-0.078%	54,506	5.6%
30	182,077	19.4%	-454,513	-19.7%	-615	-0.024%	83,318	7.2%
40	310,155	23.2%	-296,249	-16.5%	-204	-0.014%	136,544	9.7%
50	426,740	28.3%	-194,734	-12.5%	-86	-0.009%	189,481	12.6%
60	642,125	36.8%	-98,049	-9.1%	-44	-0.003%	275,057	15.3%
70	936,926	46.4%	-44,705	-5.4%	-25	-0.001%	357,546	20.7%
80	1,527,558	61.1%	-21,860	-3.3%	-9	-0.001%	588,141	28.6%
90	2,489,362	91.3%	-9,746	-1.8%	-1	0.000%	1,158,806	60.8%

Table 15: Markups Implied by Standard Model
Without Transactions Costs or Ex-Post Changes

Percentile	All Bidders		Winning Bidders Only	
	Direct Markup $(b_i\text{-}c_i)q^a$	Direct Markup / Estimate	Direct Markup $(b_i\text{-}c_i)q^a$	Direct Markup / Estimate
10	7,499.27	1.0%	29,457	4.6%
20	13,257.49	1.6%	62,968	5.7%
30	20,354.98	2.1%	89,335	8.4%
40	31,107.43	2.7%	139,978	10.0%
50	51,972.27	3.4%	215,725	12.1%
60	74,405.59	4.4%	279,412	16.2%
70	112,747.60	5.8%	386,614	21.1%
80	185,893.20	9.2%	643,819	29.6%
90	344,865.40	16.9%	1,036,313	60.5%

Table 16: Transactions Costs

Percentile	Lower Bound				Upper Bound			
	Value	As a Fraction of the Estimate	As a Fraction of the Direct Markup	As a Fraction of Ex-Post Profit	Value	As a Fraction of the Estimate	As a Fraction of the Direct Markup	As a Fraction of Ex-Post Profit
10	0	0	0	0	15,017.74	0.02670	0.11405	0.12044
20	0	0	0	0	31,751.91	0.04887	0.24860	0.30914
30	7,224.31	0.00906	0.03305	0.06791	62,659.42	0.08293	0.40116	0.58500
40	41,037.48	0.03547	0.13867	0.19074	142,739.0	0.12942	0.54035	0.92729
50	86,828.42	0.06790	0.21035	0.46725	271,700.6	0.18239	0.67880	1.31758
60	239,042.3	0.10784	0.33661	0.81578	444,468.0	0.24370	0.78135	1.72423
70	362,764.6	0.13468	0.46131	1.09496	705,118.1	0.29116	0.88826	2.28845
80	571,231.3	0.19301	0.58549	1.65807	1,183,804	0.38323	1.00649	3.07917
90	1,057,652	0.26321	0.75258	2.56246	1,979,305	0.58469	1.21379	5.89991

The lower bound for the transactions cost is calculated as $(1-\alpha_+)PosAdj + (\alpha_- -1)|NegAdj| + (\delta-1)|Ded|$. These items alter the final payment, but do not involve additional costs incurred by the contractor. It is a lower bound, for it assumes that the estimate of γ only reflects the profit margin on extra work. If we assume instead that the contractors are performing the extra work at zero profit margin, the estimate of γ reflects pure transactions costs, giving us an upper bound equal to $(1-\alpha_+)PosAdj + (\alpha_- -1)|NegAdj| + (\delta-1)|Ded| + (1-\gamma)ExtraWork$.

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(lix) This paper was presented at the ENGIME Workshop on “Mapping Diversity”, Leuven, May 16-17, 2002
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(lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003
(lxii) This paper was presented at the ENGIME Workshop on “Communication across Cultures in Multicultural Cities”, The Hague, November 7-8, 2002
(lxiii) This paper was presented at the ENGIME Workshop on “Social dynamics and conflicts in multicultural cities”, Milan, March 20-21, 2003
(lxiv) This paper was presented at the International Conference on “Theoretical Topics in Ecological Economics”, organised by the Abdus Salam International Centre for Theoretical Physics - ICTP, the Beijer International Institute of Ecological Economics, and Fondazione Eni Enrico Mattei – FEEM Trieste, February 10-21, 2003
(lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003
(lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003
(lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003
(lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003
(lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference “The Future of Climate Policy”, Cagliari, Italy, 27-28 March 2003
(lxx) This paper was presented at the 9th Coalition Theory Workshop on “Collective Decisions and Institutional Design”, organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004
(lxxi) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by Fondazione Eni Enrico Mattei and Consip and sponsored by the EU, Rome, September 23-25, 2004

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