Bidding for Incomplete Contracts: An Empirical Analysis

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Abstract

When procurement contracts are incomplete, they are frequently changed after the contract is awarded to the lowest bidder. This results in a final cost of production that differs from the initial price, and may also involve significant transaction costs due to adaptation and renegotiation. We propose a stylized model of bidding for incomplete contracts and apply it to bidding data for highway repair contracts. Reduced form regressions suggest that bidders respond strategically to contractual incompleteness and that transaction costs are an important determinant of the observed bids. We then estimate a semiparametric structural auction model that allows us to recover an estimate of transaction costs. Our estimates suggest that on average transaction costs account for about ten percent of the winning bid and we conclude that transaction costs are a significant source of inefficiency in this market. *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.[2]

It is often argued that these changes not only have an impact on the direct costs of production, but that they also impose significant transaction costs in the form of haggling, dispute resolution and opportunistic behavior. In this paper we develop a model of bidding in the face of incomplete contract design, and present evidence that the resulting transaction costs are significant in highway improvement contracts awarded by the California Department of Transportation (Caltrans). We also provide evidence that bidders respond strategically to contractual incompleteness.

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 using *unit-*

[2] 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/

price auctions. These are tailored to situations where there is little uncertainty about the measurable inputs needed for production, but there may be significant uncertainty about the *actual quantities* of each input that will be needed. Procurement starts with an engineering estimate of the quantities of each unit that will be used. Contractors then bid a per unit price for each input factor, 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 average estimated bid and the average actual ex post payment. The final payment may also differ due to a change in scope, or the overall aims 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 seventy percent larger than the winning bid.

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 that 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 taken to the data. The data we have collected has information about the initial bids, the changes made to the contract, and how the final payment was adjusted.

We begin our empirical analysis by estimating two reduced form models of bidding. The results suggest that transaction costs are significant and are an important determinant of the observed bids. For example, our estimation suggests that if the contractor expects a negative adjustment to compensation of a dollar, she will increase her bid by \$3.80, so that she is compensated \$2.80 above and beyond the direct cost of the adjustment. We also show that contractors strategically manipulate their bids in response to contractual incompleteness.

We then estimate a structural model of bidding to infer the contractors' informational rents and the transaction costs incurred to modify an incomplete contract. The results suggest that transaction costs may be an even more important determinant of the final price paid by Caltrans than the commonly discussed mark-ups resulting from the informational rents of the bidders.

This paper is related to a recent literature on the procurement process when the original contract is subject to ex post changes. The papers most closely related to our study are Bajari and Tadelis (2001), Bajari, McMillan and Tadelis (2001), Corts and Singh (2004) and Chakravarty and MacLeod (2004). Another 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. (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 (2004), Hendricks, Pinkse and Porter (2003) and Bajari and Hortacsu (2003).) We follow in this tradition by using a similar two-step approach, but with different first order conditions that incorporate the effect of anticipated changes on ex ante bidding behavior. Also, like others who have studied bidding for highway procurements, 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 misspecified 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 paper allows us to estimate contractors' private information. Athey and Levin (2001) demonstrated that if bidders are better informed about the final quantities than the government agencies administering the contract, bids will be strategically manipulated. However, their paper does not attempt to recover bidder markups. We estimate a markup and decompose it into markups over costs and profits from ex post changes in the contract due to incompleteness. Our results suggest that markups will be mismeasured, possibly severely, if we do not account for incompleteness.

Third, our paper contributes to the literature on transaction costs economics by generating estimates of transaction costs from contractual incompleteness. While transaction cost economics dates back to the original 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 transaction 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), procurements for highway construction, as well as many other procurements in the public sector, are often done through 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 completed.

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. Table 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).[3]

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 the estimated quantities. For example, the engineers might estimate that it will take 25,000 tons of asphalt to resurface the stretch of highway listed in the plans but 26,752 tons are actually used. The difference, in fact, may be substantial if there are unexpected conditions or work has to be redone or eliminated. As a result, final payments made to the contractor 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 simple sum of actual item costs given the unit prices in the 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 simple 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

[3] 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 does not 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.

thought to be due to negligence by one party, both sides will renegotiate an *adjustment of compensation*.[4] 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. A change in scope is a change in the overall description and design of the project that needs to be completed. For instance, the original scope of the project might be to resurface 2 miles of highway. However, the engineers and contractor might discover that the subsurface is not stable and that certain sections need to be excavated and have gravel added. This would constitute a change in scope. In most cases, the contractor 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, Caltrans may deduct liquidated damages. Such deductions may be a source of disputes between Caltrans and the contractor. 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 underrun 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 large unit prices

[4] 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*.

on items that are expected to overrun and unusually small unit prices on items expected to underrun.

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, 4 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. Caltrans may also 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 changes in scope 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 increase in compensation, this will lead to a $100,000 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. If this causes the project to be less attractive, they will incorporate their expectations about ex post deductions into their bidding behavior and raise some of their unit prices accordingly.

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 that are proposed by the buyer and distributed to the potential contractors. The estimated quantity for each task is q_t^e, while the actual ex post quantity that will be needed to complete the task is 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 has perfect foresight about the actual quantities $\mathbf{q}^a$ while the buyer Caltrans is unaware of $\mathbf{q}^a$ and only considers $\mathbf{q}^e$. The perfect foresight of contractors can naively be interpreted as the contractors knowing the actual $\mathbf{q}^a$. Since we will assume that contractors are risk neutral, this specification can more convincingly be interpreted as contractors not having *exact* information about $\mathbf{q}^a$, but instead having *symmetric uncertainty* about the actual quantities, resulting in symmetric 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 have symmetric 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 $\mathbf{c}^i = (c_1^i, ..., c_T^i) \in \Re_+^T$ 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. The costs (type) of contractor i are drawn from a well behaved joint density $f_i(\mathbf{c}^i)$ with support on a compact subset of $\Re_+^T$. The distributions are common knowledge, but only contractor i knows $\mathbf{c}^i$. Also costs are independently distributed conditional on publicly observed information.

This specification, together with the symmetric information that contractors have about $\mathbf{q}^a$, depicts a situation where contractors have rational expectations about what needs to be done to meet the contract (as in the most common type of procurement models) but they have private information about the costs of production.

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. This implies that our bidders participate in an auction with a simple linear scoring rule where each bid vector is transformed into a unidimensional score, the estimated price.[5]

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,

$$\pi_i(\mathbf{b}^i, \mathbf{c}^i) = \left(R(\mathbf{b}^i) - \sum_{t=1}^{T} c_t^i q_t^a \right) \left(\Pr \left\{ \sum_{t=1}^{T} b_t^i q_t^e < \sum_{t=1}^{T} b_t^j q_t^e \text{ for all } j \neq i \right\} \right)$$

where the interpretation is standard: the contractor receives the net payoff of revenue less production costs only in the event that all other bidders submit higher bids as calculated using the expected 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 symmetric 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 several sources of inefficiency. One example is bargaining with asymmetric cost information where the seller has private information about the costs of ex post changes and adjustments, as shown in Bajari and Tadelis (2001). Another source could be wasteful investments in strengthening one's bargaining position, or other wasteful influence activities that cannot be avoided in equilibrium (see Milgrom, 1988).

We choose to be agnostic about the exact source of transaction costs, which in reality are likely to be generated by a combination of several sources of bargaining frictions. Instead, we will take a first stab at

[5] See Osband and Reichelstein (1985), Che (1993), and Bushnell and Oren (1994) for early work on scoring auctions, and a recent generalization by Asker and Cantillon (2004).

[6] As mentioned earlier, another simplistic way of interpreting this is that contractors have perfect foresight of these components. An alternative assumption would be that each contractor receives a signal of this common value, which would complicate the model beyond tractability.

measuring whether transaction costs play an important role in bidding for contracts, and inject a reduced form of transaction costs into the standard model described above. We do this by introducing coefficients that will be a measure of the dissipated surplus for each of the three revenue components related to changes.

First, it is useful to distinguish between positive and negative ex post adjustments to revenues. By definition, any extra work adds compensation to the contractor while any deduction is an ex post loss incurred by the contractor.[7] This implies that $X > 0$ and $D < 0$. The adjustments A, however, can be positive or negative. For this reason we divide them so that positive adjustments are labeled $A_+ > 0$ while negative ones are labeled $A_- < 0$. We can write down the total ex post revenue as,

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

To interpret (1) first note that for positive ex post income, transaction costs will cause some fraction of the surplus to be dissipated. Therefore, the positive coefficients β_+ 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 contractual loss imposed by the adjustments or deductions. Therefore, the positive coefficients β_- 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 to avoid 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), we believe 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 skewness of the bid. Clearly, the degree of skewness will depend on what "reasonable prices" would be. In practice, Caltrans engineers collect

[7] Forced deductions are clearly a penalty. We are thus implicitly assuming that when changes in scope are agreed upon then the voluntary acceptance by the contractor implies that he is not losing money, by revealed preference.

information from past bids and market prices to create an estimate $\overline{b}_t$ that represents the engineer's estimate for the unit cost of contract item t. Thus, given a vector of prices $\mathbf{b}^i$, a natural measure of skewness would be the distance from the engineer's estimate $\overline{\mathbf{b}}$.

Let $P(\mathbf{b}^i|\overline{\mathbf{b}})$ denote the continuously differentiable penalty function of skewing bids. We impose four assumptions on $P(\mathbf{b}^i|\overline{\mathbf{b}})$. First, $P(\overline{\mathbf{b}}|\overline{\mathbf{b}}) = 0$, that is, there is no penalty from submitting a bid that matches the engineers estimates. Second, $\frac{\partial P(\mathbf{b}^i|\overline{\mathbf{b}})}{\partial b_t^i}\Big|_{b_t^i=\overline{b}_t} = 0$, which implies that when the bids match the engineer's estimates, the first order costs of skewing are zero. These two assumptions seem natural ways to capture the costs of skewed bidding given the practices of Caltrans. Third, we assume that $P(\mathbf{b}^i|\overline{\mathbf{b}})$ is strictly convex, and finally, we assume that $\frac{\partial P(\mathbf{b}^i|\overline{\mathbf{b}})}{\partial b_t^i}\Big|_{b_t^i=0}$ is very negative. These last two assumptions guarantee an interior solution to the bidders' optimization problem in the choice of $\mathbf{b}^i$.

In our empirical specification we impose the following convenient functional form,[8]

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

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,

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

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. Our model is an independent private values setting that is similar to the multidimentional-type models of Che (1993) and is in many ways a simple special case of Asker and Cantillon (2004) where the project is fixed, and the principal's (buyer's) objective trivially fixed given that the scoring rule is fixed. Similar to Che's "productive potential" and Asker and Cantillon's "pseudotype," our equilibrium behavior will be determined *as if* our bidders have a unidimensional type. The reason is that given the scoring rule, the choice of total bid, or *score* $s = \mathbf{b}^i \cdot \mathbf{q}^e$ is separable from the optimal choice of the actual bid vector $\mathbf{b}^i$.[9] As a result, the Bayesian game will have a unique pure strategy monotonic equilibrium.

[8] Strictly speaking, this does not guarantee that $\frac{\partial P(\mathbf{b}^i|\overline{\mathbf{b}})}{\partial b_t^i}\Big|_{b_t^i=0}$ is very large, but we continue to assume that an interior solution exists. The estimates of the data will act as a reasonable reality check.

[9] That is, given the costs $\mathbf{c}^i$, and given a promised score (price) s, each bidder has an optimal choice of bids *conditional on*

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 $\prod_{j\neq i} \left(1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)\right)$. Using this, as well as substituting for revenues with (2), yields the contractor's profit function,

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

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:

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

From our assumptions on the densities of types and on the penalty function, $H_j(\cdot)$ is differentiable with density $h_j(\cdot)$, and the 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 $t \in \{1, ..., T\}$,

$$\begin{aligned}\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot \mathbf{q}^a \;=\; & \frac{1}{q_t^e}\left(q_t^a - 2\alpha\left(b_t^i - \overline{b}_t\right)\left|\frac{q_t^e - q_t^a}{q_t^e}\right|\right)\left(\sum_{j\neq i} \frac{h_j(\mathbf{b}^i \cdot \mathbf{q}^e)}{1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)}\right)^{-1} \\ & + \alpha \sum_t \left(b_t^i - \overline{b}_t\right)^2 \left|\frac{q_t^e - q_t^a}{q_t^e}\right| - (1-\beta_+)A_+ - (1+\beta_-)A_- - (1-\gamma)X - (1+\delta)D\end{aligned} \tag{3}$$

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 satisfies the system (3) for all bidders $i \in N$. As stated above, there is a unique monotonic equilibrium in pure strategies, and we will therefore use (3) as the basis for our empirical analysis.

winning, $b_t^i(\mathbf{c}^i)$, and given this optimal price policy, there is an optimal score $s(\mathbf{c}^i)$ that is unidimensional. This is like Asker and Cantillon's *pseudotype*.

The first order condition (3) provides some insight into a firm's optimal bidding strategy, 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:

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

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), Hong and Shum (2002), Pesendorfer and Jofre-Bonet (2003), Bajari and Ye (2003), Campo (2004), Krasnokutskaya (2004) and Krasnokutskaya and Seim (2004)). 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 competitors are close or far from the project site, since this determines his relative advantage or disadvantage in the costs of hauling equipment and material. The markups should also depend on contractor i's uncertainty about his competitors' costs. Intuitively, we expect informational rents to increase as uncertainty about one's competitors' costs grows.

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, $-\alpha \sum_t \left(b_t^i - \overline{b}_t\right)^2 \left|\frac{q_t^e - q_t^a}{q_t^e}\right|$, 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 $-(1-\beta_+)A_+ - (1+\beta_-)A_- - (1-\gamma)X - (1+\delta)D$ also influences the total markup $\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot \mathbf{q}^a$ on installing $\mathbf{q}^a$. 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. 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 models previously imposed in both the theoretical and empirical literature, which implicitly impose the assumption that $\alpha = \beta_+ = \beta_- = \gamma = \delta = 0$. 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 and 2000. Our sample includes 414 projects with a value of \$369.2 million.[10] There were a total number of 1,938 bids submitted by 271 general contractors located primarily in California. In Table 1, we list the top 25 contractors in our data set and their market share. Over half of the participating contractors, 157 firms, never won a contract during the period. In fact, only 5 firms participated in more than 10 percent of the auctions. To account for some of this asymmetry in size and experience, we will sometimes distinguish between top firms and "fringe" firms, where fringe firms are defined as those who each won less than 1 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 33 items, though one contract has as many as 255 items. For each item, we have all bidders' unit prices, along with the estimated quantity of the item needed. Additionally, the bid summaries report the engineer's estimate of the project's 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.[11] This estimate can be thought of as $\sum_t \bar{b}_t q_t^e$, the dot product of "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 and 2000 Contract Item Cost Data Summaries, 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

[10] 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.

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

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 $t = 1, ..., T$ which we denote as $DIST_{i,t}$. The contract provides information about the location of the project, often as detailed as the cross streets at which highway construction begins and ends.[12] 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 which 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 $BACKLOG_{i,t}$ to be the remaining dollar value of contracts won but not yet completed at the time a new bid is submitted.[13] We then define $CAPACITY_i$ as the maximum backlog experienced for any day during the sample period, and the utilization rate $UTIL_{i,t}$ 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 members of the industry 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. That is, since we treat the distance from the construction site as a proxy of cost advantage, we define $RDIST_{i,t}$ as the minimum distance to the job site among bidders on project t, excluding firm i. Likewise, $RUTIL_{i,t}$ is the minimum utilization rate among bidders on project t, 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 \$3.2 million with

[12] 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.

[13] 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.

a standard deviation of $7.4 million. The difference between the first and second lowest bids averages $191,516, meaning that bidders leave some "money on the table." On average, the projects require just over four 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 $155,092, or about 5.2 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 underruns 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 $135,032. Extra work negotiated through after-contract change orders, as well as deductions, contribute to the difference, averaging $207,476 and -$9,715 respectively. Taken together, the size of these ex post changes suggests a certain degree of incompleteness in the original contracts.

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 0.987 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 t we divide each bid $\mathbf{b}^i \cdot \mathbf{q}^e$ by the engineer's estimate. We denote this normalized variable as $NBID$. 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 t. In all of our regressions, distance and fringe status are significant and have positive signs as expected. In the first two columns, however, the overall measure of goodness of fit is 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 misspecified. 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 is up to 57 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 5 percent. These numbers suggest that by ignoring ex post changes, the total payment to the contractor is often severely mismeasured in the literature.

5.2 Accounting for Changes and Transaction Costs

Our theoretical analysis suggests that the regressions in Table 10 suffer from two sources of mispecification. First, the dependent variable is the total estimated bid, $\mathbf{b}^i \cdot \mathbf{q}^e$, instead of the (expected) total bid, $\mathbf{b}^i \cdot \mathbf{q}^a$. Second, the regressions above ignore the anticipated changes to payments due to adjustments, extras and deductions.

Based on equation (3), we re-specify the reduced form regression as follows:

$$\mathbf{b}^i \cdot \mathbf{q}^a = PROXIES_i \theta_1 + A_+ \theta_2 + A_- \theta_3 + X\theta_4 + D\theta_5 + \varepsilon_i \tag{3'}$$

The $PROXIES$ included on the right hand side are intended to capture some of the costs and competitive interactions that appear in the firm's first order condition. Specifically, they include such covariates as distance, utilization rate, its rival's distance and utilization rate, the number of participating bidders, and whether the bidder is a fringe firm. By comparison with equation (3), we see that consistent estimates of θ_2 through θ_5 can be used to derive estimates of the transaction costs on ex post contract changes:

$$\begin{array}{ll} \theta_2 \equiv -(1-\beta_+) & \theta_4 \equiv -(1-\gamma) \\ \theta_3 \equiv -(1+\beta_-) & \theta_5 \equiv -(1+\delta) \end{array}$$

The above regression is estimated by least squares. As in the previous reduced form bid regression, it is appropriate to correct for heteroskedasticity related to project size by dividing through by an estimate of that size. 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 $\overline{b}_t$ for each item t by using the mean of the unit prices bid in all the contracts that appear in our data. These measures had an R^2 of 0.69 when regressed on the estimates available in the Contract Cost Data Book. Our method of averaging submitted bids to construct engineering estimates is similar to how they are constructed by professional estimating companies. Then, the total project estimate we use is the vector product of our derived $\overline{\mathbf{b}}$ and the estimated quantities $\mathbf{q}^e$.

In Table 11, we present the results of this re-specified reduced form regression. The dependent variable, which we will refer to as $NACT$, is the *actual* payment $\mathbf{b}_i \cdot \mathbf{q}^a$, divided by the project estimate. As columns I and II 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 $NACT$. For a given contract, fringe firms tend to bid slightly more than non-fringe firms. Contract fixed effects also absorb a great deal of variation in the bids, again suggesting that there is some unobserved contract-specific heterogeneity.

Next, we include the ex post changes. We use $NDED$ and NEX 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, $NPosAdj$ and $NNegAdj$, respectively (these account for A_+ and A_- in the model). Because these characteristics do not vary within a given contract, collinearity prevents us from including contract fixed effects in the same regression with these other measures. The results of the regression without these fixed effects are shown in columns III and IV. Another way to deal with this collinearity is to run the fixed effect regression in two steps. First, we regress $NACT$ on $DIST$, $FRINGE$, and contract fixed effects. Then the estimates of the fixed effects are regressed on $NDED$, NEX, $NPosAdj$ and $NNegAdj$. This method allows us to consider the impact of ex post changes while still accounting for important contract-specific unobservables. These results are presented in columns V and VI of Table 11.

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 VI of Table 11, the coefficient on $NDED$ is -7.36 which implies for our model that $\delta = 6.36$. This suggest that if contractors expect an extra dollar of deduction, they will raise their bid by \$6.36 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 transaction costs, the coefficient on deductions should be -1. The fact that the coefficient is -7.36 is consistent with there being \$6.36 of indirect costs for every dollar of deductions. On a job with a \$6,118 deduction (the median deduction assessed in our sample), this implies an increased cost to the state of almost \$40,000. For the 414 jobs that we study, this implies that deductions add \$25,580,779 to the final price paid by the state.

A similar interpretation may be given to the coefficient of -3.80 on negative adjustments, $NNegAdj$. 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 \$2.80 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 transaction 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 1.84 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 $\$2.84$ in transaction 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 transaction costs from negotiating change orders, firms 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. If there were no transaction 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 $\$1.20$, which is consistent with there being transaction costs on the order of $\$1.30$ to $\$1.40$ for every dollar of extra work. In fact, if the direct markup were greater, the transaction costs could be as high as $\$2.20$.[14]

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.[15]

We now turn to the estimation of the penalty from skewing bids. To account for expected quantity changes, we include two alternative measures that serve as proxies. PCT is the average of the percent quantity overruns on each item t in a given project. 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

[14] This upper bound on the transactions costs associated with extra work assumes a 100% profit margin on these changes in scope. That is, if each dollar negotiated in extra work was pure profit to the contractor, the observed behavior would be consistent with \$2.20 in transactions costs. In this case, extra work would be analogous to the positive adjustments in compensation in that no additional direct costs are incurred.

[15] That is, if contractors have correct (rational) expectations K^e for a change variable K, then the correct 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.

concrete. To account for this we constructed another measure, $NOverrun$, 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, $NOverrun$ 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 coefficients on both the percent overrun, PCT, and the partial dollar overrun on standard contract items, $NOverrun$, are 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.[16] The coefficient on percent overrun is 0.027, which is statistically significant at the 1% level. That is, if a contractor expected a ten percent overrun on some item, he would shade his bid up by approximately one quarter of one percent, a modest amount. When we allow for heteroskedasticity within an item code by using fixed or random item effects, the coefficient on percent overrun is similar, although with 2450 types of items, these individual effects do not add much explanatory power to the regression.

6 Structural Estimation

In this section, we propose a method for structurally estimating the model discussed in Section 3. The structural model will allow us to estimate both the transaction costs and the distortions due to private information in a way that is consistent with the primitive assumptions made in Section 3.

The estimation approach builds on the two-step nonparametric estimators discussed in Elyakime, Laffont, Loisel and Vuong (1994), Guerre, Perrigne, Vuong (2000) and Campo, Guerre, Perrigne and Vuong (2004). In the first step, we estimate $h_j(\mathbf{b}^i \cdot \mathbf{q}^e)$ and $H_j(\mathbf{b}^i \cdot \mathbf{q}^e)$, the density and cdf of the bid distributions. In the second step, we estimate the penalty from skewed bidding, α and the parameters measuring the costs of change, β_+, β_-, δ and γ. We do this by using (3) to form a moment condition. We then use a semiparametric estimation strategy along the lines discussed in Newey (1994). We consider each of these two steps in turn.

[16] We were able to obtain engineers' estimates from the Contract Cost Data Book for a large fraction of the contract items in our data. However, since they were not available for all items, we used the method 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 0.69 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.

6.1 Estimating Bid Distributions

Much of the previous econometric literature is concerned with nonparametric estimation of h_j and H_j. While a fully nonparametric approach is technically very elegant, it is not practical in our application. Since we wish to include measures of firm specific distance and other controls for cross firm heterogeneity, nonparametric approaches would suffer from a curse of dimensionality.

In our application, we will estimate $h_j(\mathbf{b}^i \cdot \mathbf{q}^e)$ and $H_j(\mathbf{b}^i \cdot \mathbf{q}^e)$ semiparametrically. We begin by first running a regression similar to those in Table 10:

$$\frac{\mathbf{b}_j \cdot \mathbf{q}^e}{\overline{\mathbf{b}} \cdot \mathbf{q}^e} = x'_{jt}B + u_t + \varepsilon_{jt}$$

where as before the dependent variable is the normalized estimated bid, and $x_{j,t}$ include the firm's distance and whether or not it is a fringe firm. We also include an auction-specific fixed effect, u_t, to control for project-specific characteristics that are observed to the bidders but not the econometrician. As Krasnokutskaya (2004) has emphasized, failure to account for this form of unobserved heterogeneity may lead to a considerable bias in the structural estimates. As a robustness check on our results, we also estimated a version of the model with random effects and found little qualitative change in our results.

Let $\widehat{B}$ denote the estimated value of B and let $\widehat{\varepsilon}_{j,t}$ 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[17]:

$$\begin{aligned} H_j(b) &\equiv \Pr\left(\frac{\mathbf{b}_j \cdot \mathbf{q}^e}{\overline{\mathbf{b}} \cdot \mathbf{q}^e} \leq \frac{b}{\overline{\mathbf{b}} \cdot \mathbf{q}^e}\right) \\ &= \Pr\left(x'_{jt}B + u_t + \varepsilon_{jt} \leq \frac{b}{\overline{\mathbf{b}} \cdot \mathbf{q}^e}\right) \equiv G\left(\frac{b}{\overline{\mathbf{b}} \cdot \mathbf{q}^e} - x'_{jt}B - u_t\right). \end{aligned} \tag{5}$$

That is, the distribution of the residuals, ε_{jt} can be used to derive the distribution of the observed bids. We estimate G using the distribution of the fitted residuals $\widehat{\varepsilon}_{jt}$, and then recover an estimate of $H_j(b)$ by substituting in this distribution in place of G. An estimate of $h_j(b)$ can be formed using similar logic. We note that both $H_j(b)$ and $h_j(b)$ will be estimated quite precisely because there are 1938 bids in our auction. Given the estimates $\widehat{H}_j$ and $\widehat{h}_j$ we generate an estimate $\left(\sum_{j \neq i} \frac{\widehat{h}_j(\mathbf{b}_i \cdot \mathbf{q}^e)}{1 - \widehat{H}_j(\mathbf{b}_i \cdot \mathbf{q}^e)}\right)^{-1}$.

[17] To conserve on notation, we do not include the auction specific random effect in the expressions below. We include the fitted value of the random effect in order to control for omitted, auction specific heterogeneity. The fitted value of the random effect may be poorly estimated when the number of bidders is small and introduce bias into our estimates. However, the parameter estimates appeared to be more sensible than a model where they were not included.

6.2 Estimating $\alpha, \beta_+, \beta_-, \delta$ and γ

Next, we turn to the problem of estimating α, β, δ and γ. We will 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 a scalar random variable $\widetilde{c}_i$, times the engineering estimate $\overline{\mathbf{b}} \cdot \mathbf{q}^a$. The assumption (6) is similar to the multiplicative structure used in Krasnokutskaya (2004) and the location-scale models considered in Hong and Schum (2001) and Bajari and Hortacsu (2003). A similar assumption is also implicit in Hendricks, Pinkse and Porter (2001) where the authors normalize lots by tract size.

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

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

We will also include two additional sources of error in equation (7). The first is that bidders may not have perfect foresight about A_+, A_-, X and D. However, if bidders are risk neutral and have rational expectations, then the first order condition simply needs to be modified to include EA_+, EA_-, EX, and ED, the expected value of changes, instead of the actual values. In our data, we do not directly observe bidders' expectations. However, we will use well known strategies from the estimation of Euler Equations (described below) to estimate the model.

A second source of error is that A_+, A_-, X and D may be endogenous because there are omitted costs that are observed by the firms, but not accounted for in our cost estimate $\overline{\mathbf{b}} \cdot \mathbf{q}^a$. We will denote these costs as ξ_i. These costs are likely to be correlated with A_+, A_-, X and D since contracts with large, ex post changes are likely to be more complicated and thus, more expensive to complete. We will use an IV approach to correct for the endogeneity of A_+, A_-, X and D. In our data set, we observe the identity of the Caltrans engineer who supervised the project. The identity of the engineer will shift the ex post changes to the contract. While Caltrans highway contracts have numerous clauses devoted to changes, because of contractual incompleteness Engineers have considerable discretion over the scope of changes and deductions. It is well known in the industry that there is considerable heterogeneity in a given engineer's propensity to make changes to the contract or impose deductions.

In order for the identity of the engineer to be a valid instrument, it must not be correlated with ξ_i. We interpret ξ_i that is not captured in an engineering cost estimate. Recall that the Caltrans engineering staff devoted considerable resources to preparing their cost estimate and that this estimate is prepared before bidding begins. Also, the final costs of the project are verifiable, so that a badly prepared cost estimate will not go unnoticed in the bureaucracy. If Caltrans engineers knew their cost estimate was severaly flawed because of ex post changes, they would have strong incentives to update the contract plans and specifications to account for these flaws and update the cost estimate. Therefore, we will assume that the engineering staff will be ignorant of ξ_i at the time they prepare an estimate. The Caltrans engineer who supervises a project must be assigned *before work begins*. Thus, to a first approximation, it appears credible to assume that ξ_i is uncorrelated with the engineer who is assigned to the project.

Given these two additional sources of error, we can rewrite (7) as:

$$\begin{aligned}
&\widetilde{c}_i - \frac{\xi_i}{\overline{\mathbf{b}} \cdot \mathbf{q}^a} + \frac{1}{\overline{\mathbf{b}} \cdot \mathbf{q}^a} \left[\begin{array}{c} (1-\beta_+)\,(A_+ - EA_+) + (1+\beta_-)\,(A_- - EA_-) + \\ (1-\gamma)\,(X - EX) + (1+\delta)(D - ED) \end{array} \right] \\
= & \left(\frac{1}{\overline{\mathbf{b}} \cdot \mathbf{q}^a}\right) \left(\mathbf{b}^i \cdot \mathbf{q}^a - \frac{q_t^a}{q_t^e} \left(\sum_{j \neq i} \frac{h_j(\mathbf{b}^i \cdot \mathbf{q}^e)}{1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)} \right)^{-1} \right) \\
& + \left(\frac{1}{\overline{\mathbf{b}} \cdot \mathbf{q}^a}\right) \left[(1-\beta_+)A_+ + (1+\beta_-)A_- + (1-\gamma)X + (1+\delta)D \right] \\
& -\alpha \left(\frac{1}{\overline{\mathbf{b}} \cdot \mathbf{q}^a}\right) \left[\sum_t \left(b_t^i - \overline{b}_t\right)^2 \left| \frac{q_t^e - q_t^a}{q_t^e} \right| - \left(\frac{2\left(b_t^i - \overline{b}_t\right)}{q_t^e} \left| \frac{q_t^e - q_t^a}{q_t^e} \right| \right) \left(\sum_{j \neq i} \frac{h_j(\mathbf{b}^i \cdot \mathbf{q}^e)}{1 - H_j(\mathbf{b}^i \cdot \mathbf{q}^e)} \right)^{-1} \right]
\end{aligned} \quad (8)$$

Equation (8) is identical to (7) except that we have brought over two additional sources of error to the left hand side. The first is ξ_i, are omitted costs and the second is a set of expectational errors (e.g.$(A_+ - EA_+)$). These terms are the difference between expected and actual changes to the contract. As in the estimation of Euler equations, estimating the structural parameters by including the realized changes in the first order conditions will not bias the parameter estimates since the expectational errors are the difference between the expected value of a random variable and its realization. We will define $\widetilde{e}_{i,t}$ as:

$$\widetilde{e}_{i,t}(\alpha, \beta, \delta, \gamma, h, H) \equiv \widetilde{c}_i - \xi_i + \frac{1}{\overline{\mathbf{b}} \cdot \mathbf{q}^a} \left[\begin{array}{c} (1-\beta_+)\,(A_+ - EA_+) + (1+\beta_-)\,(A_- - EA_-) \\ +(1-\gamma)\,(X - EX) + (1+\delta)(D - ED) \end{array} \right]$$

We will use (8) to form the moment condition below[18]:

$$m_T(\alpha,\beta,\delta,\gamma,h,H)=\frac{1}{T}\sum_{t=1}^{T}\frac{1}{N_t}\sum_{i=1}^{N_t}\widetilde{e}_{i,t}(\alpha,\beta,\delta,\gamma,h,H)(z_{i,t}-\overline{z}_{i,t})$$

where $z_{i,t}$ is the value of the instrument for bidder i in auction t.[19] We will also include the engineer's cost estimate as an instrument since it is a natural shifter of the bidding strategies and thus correlated with the right hand side variables in (8). We index the moment condition by T to emphasize that the asymptotics of our problem depend on the number of auctions in our sample growing large.

The estimation strategy that we use follows Newey (1994). Let $\widehat{h}$ and $\widehat{H}$ denote a first stage estimate of the bid densities and distributions. Let W be a positive semi-definite weight matrix. The estimator proposed by Newey is:

$$(\alpha,\beta,\delta,\gamma)=\arg\min m_T(\alpha,\beta,\delta,\gamma,\widehat{h},\widehat{H})'Wm_T(\alpha,\beta,\delta,\gamma,\widehat{h},\widehat{H})$$

Newey demonstrates that under suitable regularity conditions this estimator has normal asymptotics despite depending on a nonparametric first stage. Furthermore, the asymptotic variance surprisingly does not depend on how the nonparametric first stage is conducted, as long as it is consistent. The optimal weighting matrix can be calculated by using the inverse of the sample variance of $m_T(\alpha,\beta,\delta,\gamma,\widehat{h},\widehat{H})$ at a first stage estimate. In our application, the first stage estimates of $\widehat{h}$ and $\widehat{H}$ are quite precise given our regression coefficients since there are over 1900 individual bids. Therefore, it is quite unlikely that our first stage bid density and distribution estimates introduce significant bias into the estimates.[20]

Given estimates of $\alpha,\beta_+,\beta_-,\delta$ and γ, we can recover an estimate of contractors' implied markups. We estimate $\widehat{\mathbf{c}}^i\cdot\mathbf{q}^a$, contract i's total cost for installing the actual quantities by evaluating the empirical analogue of (3):

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[18] This follows from the moment condition that $\widetilde{e}_{i,t}$ and z_i have a covariance of zero, i.e. $Cov(\widetilde{e}_{i,t},z_i)=0$,

[19] Obviously, we can only use those engineers that supervise more than one project as an instrument.

[20] Admittedly, we potentially introduce a bias into our estimates through the inclusion of auction specific fixed effects. The inclusion of the fixed effects may introduce a nuisance parameter problem into our estimates. However, the strategies proposed in the literature for dealing with unobserved heterogeneity (e.g. Krasnokutskaya (2004)) are not straightforward to apply to our more complicated framework. We found the estimates that controlled for unobserved heterogeneity lead to lower implied markups than estimates without fixed effects, consistent with the biases found in Krasnokutskaya (2004). Despite their limitations, we find the fixed effect estimates more plausible. We also found that random effects generated similar results.

$$\left(\mathbf{b}^i - \widehat{\mathbf{c}}^i\right) \cdot \mathbf{q}^a = \frac{q_t^a - 2\hat{\alpha}\left(b_t^i - \overline{b}_t\right)\left|\frac{q_t^a - q_t^e}{q_t^e}\right|}{q_t^e} \left(\sum_{j \neq i} \frac{\hat{h}_j(\mathbf{b}^i \cdot \mathbf{q}^e)}{1 - \hat{H}_j(\mathbf{b}^i \cdot \mathbf{q}^e)}\right)^{-1}$$

$$+\hat{\alpha} \sum_t \left(b_t^i - \overline{b}_t\right)^2 \left|\frac{q_t^a - q_t^e}{q_t^e}\right| - (1 - \widehat{\beta}_+)A_+ - (1 + \widehat{\beta}_-)A_- - (1 - \widehat{\gamma})X - (1 + \widehat{\delta})D \quad (9)$$

Using our estimates of $\widehat{H}$, $\widehat{h}$, $\widehat{\alpha}$ and $\widehat{\beta}_+, \widehat{\beta}_-, \widehat{\gamma}$ 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 already estimated.

7 Results

We summarize the structural estimates in Tables 13-16. Table 13 reports the parameter values from our semiparametric GMM estimator. The tranaction cost estimates are similar to the reduced form estimates discussed in Section 5. For instance, the second column of Table 13 implies that every dollar the contractor receives for a positive adjustment generates \$1.66 of transaction costs. Recall that our results control for the quantities that were actually installed by the contractor, $\overline{\mathbf{b}} \cdot \mathbf{q}^a$. Moreover, as we described in the previous section, we have instrumented for the endogeneity of positive adjustments to account for a possible bias from omitted cost variables. Therefore, we argue that this estimate reflects transaction costs instead of omitted costs ξ_i.

Our other parameter estimates are also consistent with the presence of significant transaction costs. A dollar of deductions generates \$8.77 in transaction costs and a dollar of negative adjustments generates \$12.07 in transaction costs. While these numbers are large, the average negative adjustments in our sample is only about \$3149 and the average negative deduction is \$9,714. Therefore, while the marginal effect of these variables are quite large, their total contribution to project costs is modest. The engineering staff at Caltrans would have an incentive to economize on negative adjustments and deductions if they believed these variables generate large transaction costs as our estimates suggest.

The estimated value of the skewing parameter, α is -2.2535E-06. This estimate is statistically significant and different from the sign predicted by our theoretical model. However, it is extremely small in monetary terms and has no appreciable impact on profits or overall costs. The result that there are small penalties from skewing is quite robust to alternative specifications for the functional form of the skewing penalty penalty. However, recall from Section 4 that positive and negative adjustments are essentially due to renegotiating unit prices. As an empirical matter, it may be difficult to separately identify a quadratic effect of overruns and underruns, as captured in α, from the linear effect captured in β_+ and β_-.

In Tables 14a and 14b, we summarize our estimates of bidders markups. Our results suggest that the industry is quite competitive. The median profit margin is 3.6 percent for all bids and 11.9 percent for winning bids. We note that Granite Construction Inc. the largest bidder in our data is a publicly traded company and reports a net profit margin of 2.91 percent. The construction industry average according Standard and Poors is 1.9 percent. Profit margins based on SEC filings and our conception of profits differ in many respects. However, the available direct evidence on profit margins suggests that the construction industry is quite competitive and our results are consistent with this evidence.

Markups over direct costs $\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot \mathbf{q}^a$ are considerably higher than the profit margin. The median markup over direct costs, $\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot \mathbf{q}^a$ is \$254,311 for all bids and \$491,083 for winning bids. The ratio of the markup to the estimate for the median job is 18.1 percent for all bids and 29.2 percent for winning bids.

In Table 15, we compare the estimates in Table 14 with the estimated markups found using more standard methods. Using our first stage estimates of $\hat{H}_j(\mathbf{b}_i \cdot \mathbf{q}^e)$ and $\hat{h}_j(\mathbf{b}_i \cdot \mathbf{q}^e)$, we evaluate the empirical analogue of equation (4), which is essentially the estimator discussed in Guerre, Perrigne and Vuong (2000). 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 total markup is \$224,788, or 12.1% of the estimate for winning bidders. This is almost exactly the median profit margin estimated in Table 14. By comparing the first order conditions to the two models, this should not be surprising. The only difference in the net profit margin under the two approaches should come from the skewing penalty and the discrepancies between estimated and actual item quantities. Ex post changes will shift the bid, but do not alter the contractors' profits.

8 Discussion

8.1 Lessons for Auction Design

Our estimates imply some perhaps surprising lessons for the design of these 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 1938 bids priced contract items so that, if he did win the contract, he could expect a profit of \$52,127, or 3.6% 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 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 transaction costs erode more than any positive gains through change orders, they skew their bids upward to extract high rents on prespecified contract items. Among winning bidders, the median value of this direct markup, $(\mathbf{b}_i - \mathbf{c}_i) \cdot \mathbf{q}^a$, is 29.2 percent of the project estimate.

Second, our estimates imply that transaction costs are important. Implied transaction costs on different types of final payment changes range from two dollars to over ten 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 transaction costs on each contract. These bounds are determined based on the possible margins that firms may collect on extra work through change orders. The lower bound is calculated as $2.6602A_+ + 12.0712|A_-| + 1.5216X + 8.7111|D|$ and the upper bound is calculated as $2.6602A_+ + 12.0712|A_-| + 2.5216X + 8.7111|D|$. The upper and lower bound differ by the coefficient on X. Suppose that the contractor was able to earn a profit margin from renegotiating changes as reflected in X. Our upper bound on profits from renegotiating the contract was $1 for every $1 of changes in scope. This would imply that the transaction costs for renegotiating X were 2.5216 because firms receive an extra dollar of profits for every extra dollar in X.[21]

The median estimate of transaction costs is a significant component of costs by any standard. It has a lower bound of 14.6 (8.3,20.9) percent of the estimate and an upper bound of 18.1 (12.4,23.9) percent of the estimate. We conclude that transaction costs account for a signficant portion of total project costs. These numbers might be surprising in the context of the existing economics literature which has emphasized private information and moral hazard as the main sources of departures from efficiency in procurement.

However, this result is consistent with current thinking in Construction and Engineering Project Management. (See Bartholomew (1998), Clough and Sears (1994), Hinze (1993) and Sweet (1994). Also see Bajari and Tadelis (2001) for a more complete set of references and discussion of the literature). One of the central concerns emphasized in this literature are methods for minimizing the costs of disputes between contractors and buyers. The topic of controlling contractor magins by comparison receives relatively little emphasis in this literature.

Our results suggest that the focus on the literature is appropriate for this industry. Contractor margins are estimated to be fairly modest. Apparently, competitive bidding and free entry do a good job of keeping profits low. Our results suggest that reducing transaction cost is probably the most important source of potential improvements to efficiency. An implication of equation (3) is that Caltrans is ultimately responsible for transaction costs on the project, as they are directly passed on from the bidders. Ex post changes that are anticipated do not change contractor profits or losses.

[21] Industry sources suggest that a twenty percent profit margin on change orders is most common. It is helpful to recall that our cost estimate controls for the quantities actually installed and that positive and negative adjustments are effectively changes to compensation from the unit prices. Hence, these are a pure transfer and do not involve additional costs that we have not controlled for in our cost estimate.

Summing over all 414 contracts in our data, the lower bound suggests that Caltrans spent $189 million on transaction costs in 1999 and 2000. The average ratio of the transaction costs to the winning bid is 0.1048. Even half of this number would be substantial. In the construction industry, much of the innovation in contract forms has been directed at making sure that contractors and buyers work together as a team and that they don't squander resources on haggling over changes to the contract. We note that this topic has received relatively little attention in theoretical literature on procurement and might be an important area for future research.

8.2 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 transaction costs. These results are consistent with Bajari and Tadelis (2001) and Bajari, McMillan and Tadelis (2003) where we argued, heavily citing industry sources, that transaction costs are a key determinant of contract form and award mechanism in private sector construction. We noted 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 transaction costs. We interpret our finding as further empirical evidence that transaction costs are one of the leading disadvantages of the traditional competitive bidding system.

To the best of our knowledge, this is the first paper to use a structural model to recover estimates of transaction costs. Our results suggest that these transaction costs are an important determinant of observed bidding behavior. Therefore, structural models that fail to account for these costs might generate considerable biases in parameter estimates. Finally, our results suggest that commonly used reduced form bid functions are misspecified and thus biased when changes occur. The reduced form bid functions must control for ex post changes to the contract and the dependent variable should be the total bid using the actual quantities as weights.

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Table 1: Identities of Top 25 Firms

Firm ID	Firm Name	Market Share	Firm ID	Firm Name	Market Share
104	Granite Construction Company	27.2%	82	Excel Paving Company	1.5%
75	E L Yeager Construction Co Inc	10.4%	186	Pavex Construction	1.3%
135	Kiewit Pacific Co	6.6%	184	Parnum Paving Inc	1.2%
147	M C M Construction Inc	6.5%	23	Baldwin Contracting Company Inc	1.1%
125	J F Shea Co Inc	3.3%	162	Mercer Fraser Company	1.0%
244	Teichert Construction	3.3%	248	Tidewater Contractors Inc	1.0%
262	W Jaxon Baker Inc	2.9%	22	B E C Construction Co	0.9%
12	All American Asphalt	2.2%	126	J McLoughlin Engineering Co Inc	0.8%
251	Tullis And Heller Inc	2.1%	88	Ford Construction Co Inc	0.8%
237	Sully Miller Contracting Co	1.9%	96	George Reed Inc	0.7%
265	West Coast Bridge Inc	1.9%	87	FNF Construction	0.7%
25	Banshee Construction Co Inc	1.8%	253	Union Asphalt Inc	0.7%
107	Griffith Company	1.6%		**TOTAL**	**83.6%**

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)
104	76	343,987,526	378,629,804	244	58.9%	3,966,908	3,928,872	36.6	47.4
75	13	132,790,460	144,975,251	31	7.5%	8,607,538	8,610,249	61.0	70.6
135	5	112,057,627	92,031,048	30	7.2%	15,254,801	14,798,046	151.5	158.9
147	2	89,344,972	90,384,704	6	1.4%	21,952,372	22,397,538	72.6	77.8
125	9	43,030,861	46,506,051	40	9.7%	3,710,768	3,512,680	91.3	108.4
244	16	40,177,076	45,533,624	43	10.4%	3,104,075	2,915,690	40.6	52.3
262	13	37,702,631	40,808,024	65	15.7%	3,236,153	3,293,634	141.8	170.0
12	14	30,764,962	30,726,217	33	8.0%	2,425,688	2,429,789	24.0	29.7
251	10	27,809,535	28,651,380	16	3.9%	2,406,761	2,612,752	32.2	38.9
237	17	27,889,186	27,025,850	49	11.8%	2,389,932	2,386,667	54.4	59.9
265	4	26,786,493	26,426,965	9	2.2%	7,283,186	7,406,581	234.5	214.4
25	2	23,118,363	24,624,599	7	1.7%	5,448,318	5,467,099	40.4	43.3
107	8	21,981,980	22,706,554	26	6.3%	3,524,629	3,758,627	36.1	42.6
82	3	17,763,635	20,315,232	33	8.0%	2,045,813	1,907,715	24.2	28.7
186	7	17,160,757	18,050,388	22	5.3%	1,809,050	1,719,094	25.2	28.7
184	12	14,997,849	17,196,784	25	6.0%	1,780,978	1,869,706	84.6	106.9
23	5	14,178,601	15,726,516	21	5.1%	2,927,704	2,746,659	47.3	63.7
162	8	12,379,191	13,483,870	17	4.1%	1,557,772	1,570,402	37.0	47.5
248	3	11,256,234	13,258,546	3	0.7%	3,752,078	4,588,278	10.0	14.0
22	7	11,855,713	12,664,796	10	2.4%	2,333,166	2,215,831	98.7	128.1
126	2	11,258,867	11,390,486	18	4.3%	1,765,946	1,801,236	56.1	55.4
88	1	9,674,380	10,711,489	2	0.5%	8,567,932	8,500,931	87.5	102.5
96	6	9,244,215	10,290,260	18	4.3%	1,572,904	1,551,537	33.5	52.7
87	1	10,498,536	10,153,836	13	3.1%	12,431,695	12,434,916	388.2	380.9
253	6	9,042,273	9,394,612	12	2.9%	2,279,318	2,466,966	38.8	46.1

Table 3: Comparison Between Fringe Firms and Firms with Over 1% Market Share

	Fringe Firms	Non-Fringe Firms
Number of Firms	254	17
Number of Wins	198	216
Number of Bids Submitted	1238	700
Average Bid Submitted	$ 3,389,984.75	$ 5,404,392.50
Average Distance to Job Site (miles)	79.0	70.5
Average Travel Time to Job Site (minutes)	87.5	79.0
Average Capacity	$ 949,141.10	$ 33,243,336.00
Average Backlog at Time of Bid	$ 126,114.10	$ 7,725,654.00

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
DIST1	47.47	60.19	0.27	413.18	DIST6	88.21	115.84	0.74	695.43
DIST2	73.55	100.38	0.19	679.14	DIST7	88.46	119.97	0.85	570.27
DIST3	75.47	95.56	0.13	594.16	DIST8	73.91	75.85	4.47	259.09
DIST4	84.38	89.87	1.45	494.08	DIST9	105.86	104.31	3.41	495.67
DIST5	76.12	86.33	1.25	513.31	DIST10	69.72	80.20	7.35	294.97

DIST1 is the distance of the lowest bidder, DIST2 is the distance of the second lowest bidder, and so on.

Table 5: Travel Time to Job Site (in minutes)

	Mean	Std. Dev.	Min	Max		Mean	Std. Dev.	Min	Max
TIME1	56.95	64.28	1.00	411.00	TIME6	97.28	119.61	2.00	767.00
TIME2	82.51	97.51	1.00	614.00	TIME7	97.30	119.11	1.00	530.00
TIME3	85.86	97.44	0.00	580.00	TIME8	85.81	79.78	8.00	267.00
TIME4	94.04	89.82	4.00	449.00	TIME9	117.42	105.33	7.00	509.00
TIME5	85.92	85.39	5.00	458.00	TIME10	81.56	80.97	12.00	287.00

TIME1 is the distance of the lowest bidder, TIME2 is the distance of the second lowest bidder, and so on.

Table 6: Bid Concentration Among Contracts Awarded to Lowest Bidder

Number of Bidders	2	3	4	5	6	7	8	9	10	11+	Total
Contracts in 1999	21	47	36	30	11	8	4	2	3	0	162
Contracts in 2000	31	46	49	43	31	19	8	12	6	7	252

Table 7: Project Distribution throughout the Year

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Contracts in 1999	13	11	19	12	18	18	24	20	13	4	8	2
Contracts in 2000	12	14	23	36	16	26	10	39	25	22	20	9

Table 8: Summary Statistics

	Obs	Mean	Std. Dev.	Min	Max
Across Contracts Under Consideration					
Winning Bid	414	3,203,130	7,384,337	70,723	86,396,096
Markup: (Winning Bid-Estimate)/Estimate	414	-0.0617	0.1763	-0.6166	0.7851
Normalized Bid: Winning Bid/Estimate	414	0.9383	0.1763	0.3834	1.7851
Second Lowest Bid	414	3,394,646	7,793,310	84,572	92,395,000
Money on the Table: Second Bid-First Bid	414	191,516	477,578	68	5,998,904
Normalized Money on the Table: (Second Bid-First Bid)/Estimate	414	0.0679	0.0596	0.0002	0.3476
Number of Bidders	414	4.68	2.30	2	19
Distance of the Winning Bidder	414	47.47	60.19	0.27	413.18
Travel Time of the Winning Bidder	414	56.95	64.28	1.00	411.00
Utilization Rate of the Winning Bidder	414	0.1206	0.1951	0.0000	0.9457
Distance of the Second Lowest Bidder	414	73.55	100.38	0.19	679.14
Travel Time of the Second Lowest Bidder	414	82.51	97.51	1.00	614.00
Utilization Rate of the Second Lowest Bidder	414	0.1401	0.2337	0.000	0.9959
Across Bids Submitted					
Normalized Bid	1938	1.0474	0.2685	0.3834	7.8611
Distance to Job Site	1938	72.37	91.93	0.13	695.43
Travel Time to Job Site	1938	81.93	92.29	0.00	767.00
Backlog at Time of Bid	1938	5,453,880	16,433,078	0.00	1.503e+08
Capacity	1938	25,590,740	49,856,236	0.00	1.510e+08
Utilization (Backlog/Capacity)	1938	0.1221	0.2266	0.0000	0.9965
Minimal Distance Among Rivals	1938	26.70	36.60	0.13	618.62
Minimal Travel Time Among Rivals	1938	35.15	41.98	0.00	592.00
Minimal Utilization Among Rivals	1938	0.0226	0.0894	0.0000	0.9806

Table 9: Importance of Ex-Post Changes

	Obs	Mean	Std. Dev.	Min	Max
Adjustments	414	135,032	681,068	-178,183	12,142,414
Adjustments / Estimate	414	0.0242	0.0493	-0.2172	0.3962
Extra Work	414	207,476	706,372	0	12,271,703
Extra Work / Estimate	414	0.0628	0.0837	0	0.5960
Deductions	414	-9,715	47,933	-796,071	0
Deduction / Estimate	414	-0.0027	0.0093	-0.0698	0
CCDB Overrun = (ActQ-EstQ)*CCDB price	414	-67,040	502,017	-9,462,806	506,575
CCDB Overrun / Estimate	414	-0.0327	0.3186	-6.3401	0.1610
Final Payment-Winning Bid	414	155,092	1,503,604	-24,111,356	13,747,552
(Final Payment-Winning Bid) / Estimate	414	0.0523	0.1249	-0.6591	0.6530

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 engineer's estimate was used to normalize this and the other measures.

Table 10: Standard Bid Function Regressions

Variable	I.	II.	III.	IV.	V.
$DIST_{i,t}$	0.00019	0.00019	0.00019	0.00006	0.00019
	(3.22)	(3.09)	(3.85)	(0.73)	(3.01)
$RDIST_{i,t}$	-0.00016	-0.00021	-0.00028	-0.00010	-0.00020
	(-1.35)	(-1.78)	(1.99)	(-0.76)	(-1.10)
$UTIL_{i,t}$		0.03602	0.04072	0.07128	0.03774
		(1.31)	(1.61)	(2.51)	(1.52)
$RUTIL_{i,t}$		-0.12067	-0.03181	-0.13558	-0.04310
		(-2.54)	(-0.64)	(-2.66)	(-0.58)
$FRINGE_i$		0.04794	0.03727		0.03700
		(3.85)	(4.56)		(3.14)
N_t		-0.01191		-0.01274	
		(-6.99)		(5.47)	
Constant	1.03793	1.07645	1.01332	1.11427	1.01947
	(111.47)	(70.93)	(94.20)	(63.11)	(68.23)
Fixed/Random Effects	No	No	Project FE	Firm FE	Project RE
R^2	0.0044	0.0218	0.5325	0.1981	0.0071
Number of Obs.	1938	1938	1938	1938	1938

The dependent variable is the total bid divided by the engineer's 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	I.	II.	III.	IV.	V.	VI.
$DIST_{i,t}$	0.00020	0.00015	0.00021	0.00013	0.00019	0.00019
	(1.52)	(3.00)	(1.67)	(1.11)	(4.19)	(4.19)
$RDIST_{i,t}$	0.00063	-0.00038				
	(2.27)	(-2.45)				
$UTIL_{i,t}$	-0.00587	0.03618				
	(-0.11)	(1.99)				
$RUTIL_{i,t}$	0.08879	-0.04584				
	(0.69)	(-0.82)				
$FRINGE_i$	-0.00466	0.03100	-0.04448	-0.03400	0.02657	0.02657
	(-0.19)	(3.93)	(-1.98)	(-1.54)	(3.43)	(3.43)
N_t	-0.03031					
	(-7.67)					
$NPosAdj_t$			1.57042	1.78402	1.63960	1.84451
			(6.41)	(7.93)	(6.61)	(8.13)
$NNegAdj_t$			-3.71090	-3.76479	-3.74572	-3.79619
			(-7.78)	(-7.74)	(-7.80)	(-7.70)
NEX_t			0.95659	1.19168	0.96056	1.19864
			(6.12)	(9.64)	(6.11)	(9.67)
$NDED_t$			-7.35854	-7.35471	-7.38579	-7.36282
			(-9.11)	(-9.00)	(-9.16)	(-9.03)
PCT_t			0.12582		0.12563	
			(3.44)		(3.40)	
$NOverrun_t$				0.90527		0.91179
				(15.58)		(15.83)
Constant	1.14662	0.97583	0.89163	0.89748	0.96899	0.96899
	(36.51)	(107.06)	(39.09)	(40.52)	(160.46)	(160.46)
Fixed Effects	No	Project FE	No	No	Project FE	Project FE
R^2	0.0387	0.9324	0.0935	0.1357	0.9134	0.9134
Num. of Obs.	1938	1938	1938	1938	1938	1938

The dependent variable is the vector 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. 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 vector product of the CCDB prices (where available) and the difference between actual and estimated quantities. 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). The estimation was also performed using project random effects, but there was little difference in the estimates. Those results are not reported here.

Table 12: Skewed Bidding Regressions

Variable	OLS	Item Code Fixed Effects	Item Code Random Effects
Percent unit overrun	0.0265 (3.79)	0.0293 (5.52)	0.0265 (5.37)
Constant	0.9994 (161.17)	0.9993 (157.10)	0.9994 (160.14)
R^2	0.0004	0.0007	0.0004
Number of Obs.	65058	65058	65038

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: Structural Estimation

	Consistent GMM	Efficient GMM	Consistent GMM	Efficient GMM
Parameter Estimates				
PosAdj$_t$ $(1-\beta_+)$	-2.8790	-1.6602	-3.9141	-1.7213
		(0.4941)		(0.4897)
NegAdj$_t$ $(1+\beta_-)$	3.2433	13.0712	3.9582	13.3799
		(3.5828)		(3.3294)
EX$_t$ $(1-\gamma)$	-0.1925	-1.5216	-0.2695	-1.8811
		(0.4077)		(0.3967)
DED$_t$ $(1+\delta)$	11.1010	9.7111	11.9661	9.6129
		(3.6664)		(3.3389)
Skewing Parameter				
α	-4.1617E-06	-2.2535E-06	-5.6233E-06	-2.3492E-06
		(8.01E-07)		(8.57E-07)
Implied Marginal Transaction Costs				
Positive Adj.	3.8790	2.6602	4.9141	2.7213
		[1.6917, 3.6287]		[1.7615, 3.6811]
Negative Adj.	2.2433	12.0712	2.9582	12.3799
		[5.0489, 19.0935]		[5.8542, 18.9056]
Extra Work **	1.1925	2.5216	1.2695	2.8811
		[1.7224, 3.3208]		[2.1036, 3.6586]
Deductions	10.101	8.7111	10.9661	8.6129
		[1.5249, 15.8973]		[2.0687, 15.1571]
Number of Obs	1938	1938	1938	1938
Instruments Used in Second Stage GMM	Resident Engineer	Resident Engineer	Resident Engineer, Engineer's Estimate	Resident Engineer, Engineer's Estimate

** These estimates represent an upper bound on transaction costs associated with changes in scope. They do not account for marginal costs associated with performing the extra work, which for a reasonable profit margin of 20 percent would lower our estimate by $0.80.
Consistent GMM estimates were computed using the identity matrix as the weighting matrix. In a second step, efficient GMM estimates were computed using the optimal weighting matrix derived from the variance of the sample moments in the first step. Standard errors were computed for the efficient estimator, and they appear in parentheses. These were also used to derive 95% confidence intervals (in brackets) for the implied transaction costs.

Table 14a: Markup Decomposition (All Bidders)

Percentile	Direct Markup $(b_i\text{-}c_i)q^a$	Direct <u>Markup</u> Estimate	Ex-Post Changes $A+X+D-TC(A_+,A_-,X,D)$	Ex-Post <u>Changes</u> Estimate	Skewing Penalty $\alpha \cdot \sum_t[(b_i\text{-}b)^2 \lvert\%Over_t\rvert]$	Skewing <u>Penalty</u> Estimate	Total Profit π	Total <u>Profit</u> Estimate
10	26,080	5.8%	-1,250,830	-40.6%	-135.16	-0.0088%	6,176	1.3%
20	54,117	9.1%	-647,812	-28.1%	-18.63	-0.0012%	11,392	1.8%
30	101,028	11.9%	-383,068	-20.7%	-6.24	-0.0003%	18,966	2.2%
40	175,646	14.1%	-230,172	-16.4%	-1.89	-0.0001%	31,073	2.8%
50	254,311	18.1%	-178,137	-11.4%	-0.60	0.0000%	52,127	3.6%
60	374,272	22.9%	-105,839	-9.6%	-0.21	0.0000%	82,845	4.6%
70	556,655	28.5%	-55,993	-7.4%	-0.08	0.0000%	131,306	6.0%
80	961,665	38.1%	-28,053	-4.6%	-0.02	0.0000%	227,667	8.7%
90	1,870,754	55.8%	-11,860	-2.2%	0.00	0.0000%	487,750	16.2%

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

Percentile	Direct Markup $(b_i\text{-}c_i)q^a$	Direct <u>Markup</u> Estimate	Ex-Post Changes $A+X+D-TC(A_+,A_-,X,D)$	Ex-Post <u>Changes</u> Estimate	Skewing Penalty $\alpha \cdot \sum_\tau[(b_i\text{-}b)^2 \lvert\%Over_t\rvert]$	Skewing <u>Penalty</u> Estimate	Total Profit π	Total <u>Profit</u> Estimate
10	58,668	12.1%	-1,356,185	-41.5%	-128.89	-0.0068%	32,351	5.4%
20	126,980	15.7%	-771,265	-29.3%	-14.43	-0.0007%	61,427	6.4%
30	230,937	18.6%	-486,765	-21.7%	-4.98	-0.0002%	102,013	7.8%
40	338,568	23.6%	-284,847	-16.7%	-1.47	-0.0001%	154,834	9.8%
50	491,083	29.2%	-193,573	-11.6%	-0.59	0.0000%	225,931	11.9%
60	682,536	35.6%	-132,528	-9.6%	-0.20	0.0000%	295,515	14.8%
70	1,032,579	42.8%	-68,173	-7.2%	-0.09	0.0000%	425,906	20.4%
80	1,462,602	56.2%	-30,032	-4.6%	-0.03	0.0000%	711,475	27.1%
90	2,838,608	89.9%	-13,920	-2.4%	-0.01	0.0000%	1,259,569	50.7%

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

Percentile	All Bidders		Winning Bidders Only	
	Direct Markup $(b_i\text{-}c_i)q^a$	Direct <u>Markup</u> Estimate	Direct Markup $(b_i\text{-}c_i)q^a$	Direct <u>Markup</u> Estimate
10	6,001	1.3%	35,121	5.3%
20	11,547	1.8%	62,601	6.4%
30	19,067	2.2%	103,610	8.1%
40	30,829	2.8%	153,438	9.9%
50	51,167	3.6%	224,788	12.1%
60	82,976	4.4%	298,660	15.3%
70	132,191	5.9%	419,576	19.7%
80	224,722	8.8%	672,689	27.2%
90	464,602	15.8%	1,143,994	50.7%

Table 16: Transaction Costs

Lower Bound

Percentile	Total Transaction Costs	As a Fraction of the Estimate	As a Fraction of the Estimated Ex-Post Profit
10	13,952	2.5%	12.2%
	[6,624, 21,280]	[1.1%, 4.0%]	[6.0%, 18.3%]
20	32,011	5.3%	28.2%
	[16,076, 47,945]	[2.5%, 8.0%]	[16.0%, 40.5%]
30	74,297	8.1%	45.8%
	[46,029, 102,564]	[3.8%, 12.3%]	[24.5%, 67.1%]
40	142,054	10.6%	69.4%
	[54,049, 230,060]	[4.5%, 16.8%]	[34.1%, 104.7%]
50	215,862	14.6%	102.2%
	[118,958, 312,767]	[8.3%, 20.9%]	[48.5%, 155.8%]
60	348,860	18.7%	144.0%
	[211,132, 486,588]	[10.4%, 26.9%]	[74.2%, 213.9%]
70	589,379	25.3%	211.3%
	[251,585, 927,174]	[14.2%, 36.4%]	[119.6%, 303.1%]
80	919,457	33.0%	296.7%
	[440,170, 1,398,744]	[16.4%, 49.6%]	[140.9%, 452.5%]
90	1,597,358	46.5%	454.1%
	[810,019, 2,384,696]	[29.0%, 64.0%]	[230.3%, 677.9%]

Upper Bound

Percentile	Total Transaction Costs	As a Fraction of the Estimate	As a Fraction of the Estimated Ex-Post Profit
10	21,231	3.8%	18.8%
	[3,716, 38,745]	[2.6%, 5.1%]	[12.8%, 24.7%]
20	48,122	7.4%	37.8%
	[30,602, 65,641]	[5.1%, 9.8%]	[25.8%, 49.8%]
30	102,277	10.3%	66.2%
	[65,848, 138,706]	[6.8%, 13.7%]	[45.0%, 87.3%]
40	184,458	13.7%	92.1%
	[123,341, 245,575]	[9.3%, 18.0%]	[47.8%, 136.4%]
50	303,980	18.1%	138.5%
	[189,191, 418,768]	[12.4%, 23.9%]	[73.6%, 203.4%]
60	435,993	24.9%	184.0%
	[297,375, 574,612]	[16.2%, 33.5%]	[122.2%, 245.9%]
70	676,961	32.5%	266.4%
	[436,210, 917,711]	[14.9%, 50.0%]	[171.6%, 361.1%]
80	1,165,243	42.4%	387.3%
	[731,545, 1,598,940]	[27.1%, 57.6%]	[256.8%, 517.8%]
90	2,024,909	59.6%	587.0%
	[1,321,579, 2,728,239]	[38.2%, 81.1%]	[123.6%, 1050.4%]

The transaction cost is calculated as $2.6602\ (A_+) + 12.0712\ |A_-| + 1.5216\ (X) + 8.7111\ |D|$. We consider this to be a lower bound because it attributes much of the coefficient on extra work to marginal costs of production, rather than pure transaction costs. This amounts to an assumption that firms perform extra work at a zero percent profit margin. Each dollar awarded through a change in scope just covers the cost of performing that work. With \$1 of marginal costs for every \$1 of extra work, that leaves approximately \$1.52 to be explained by transaction costs. The other extreme would be to assume a 100% profit margin on extra work, making it analogous to positive adjustments in compensation. This upper bound is calculated as $2.6602\ (A_+) + 12.0712\ |A_-| + 2.5216\ (X) + 8.7111\ |D|$. 95% confidence intervals, appearing in brackets, were calculated by taking the lower and upper confidence bounds of the parameter estimates and using them in the transaction cost equation instead of the point estimates.