Contract Modification and Bidding in Highway Procurement Auctions[*]

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Abstract

Government procurement contracts for complex goods such as defense systems and infrastructure projects are generally viewed as incomplete, as changes to contract terms are common in the production phase. Using data on highway procurement auctions, recent empirical research shows that bidders incorporate the likelihood of contract modifications into their bidding strategies, factoring in the potential for costly renegotiation at bid submission. This paper investigates changes in bidding behavior and procurement costs in highway construction auctions following a shift in management practices affecting the likelihood of contract renegotiation. That shift pertained to an explicit reduction in the budgets supporting contract revisions, known as change orders, by the procurement agency. Our estimates indicate the reduction in the volume of change order activity resulted in a decline in project costs for the procuring agency in the range of 2.2 to 6.5 percent. This decline in contract modifications was also accompanied by improvements in on-time and on-budget performance, suggesting a pathway to reduce contractual costs and increase efficiency.

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1 Introduction

In procurements auctions, the government is often purchasing a complex set of goods and services from a vendor. This is particularly the case in highway construction auctions where the government procures a project that is a bundle of goods and services delivered over an extended period of time. Such procurement contracts are generally viewed as incomplete. The sources of incompleteness come, in part, from the complex nature of construction projects. While construction plans provide great detail, they cannot fully describe the complete set of tasks that make up a project and all the associated contingencies. Errors and omissions occur in plans and site conditions can vary from the original descriptions. Another source of incompleteness can arise due to management practices. The procurement agency may alter the scope of the projects, may alter design elements in the field, or adjust their flexibility in allowing substitution among building materials. Both sources of incompleteness often involve renegotiation in contract terms and changes in final payments. This paper examines how such contract modifications affect bidding and costs in highway procurement auctions focusing, in particular, on the role that management practices play in contractual incompleteness.

Recent research finds that bidders incorporate the likelihood of contract modifications into their bid submissions. Bajari, Houghton and Tadelis (2014) (hereafter BHT) analyze paving projects in California and develop a model that builds change orders into the bidder's optimization problem.[1] The empirical results indicate that bidders substantially increase their bids in response to the likelihood that modifications will occur and modeling efforts that do not account explicitly for renegotiation are misspecified.[2] The authors interpret their main findings as evidence that significant *adaptation* costs must be incurred when projects are modified post-bid letting. The main idea is that changes to a project in the field results in disruptions and costly renegotiations for contractors. Firms assess the likelihood of such modifications and incorporate these expectations of disruptions into their bids. Jung, Kosmopoulou, Lamarche and Sicotte (2014) (hereafter JKLS) examine construction contracts using Vermont bid-letting data. The focus in this paper is on esti-

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[1] Change orders are amendments to a contract that are issued by the procuring agency. In the highway procurement setting, these typically describe adjustments to the scope, design, materials employed, and the timing and nature of tasks set out in the original contract.

[2] There is a large literature that does not take into account contract modifications post-bid letting in this setting including, for example, Porter and Zona (1993), Jofre-Bonet and Pesendorfer (2000), Marion (2007), De Silva, Dunne, Kankanamge, and Kosmopoulou (2008), and De Silva, Kosmopoulou and Lamarche (2009).

mating differences in markups between auctions that involve renegotiations and auctions that do not. The authors show that markups are generally higher in auctions that have renegotiated tasks and this is driven specifically by higher markups on the renegotiated components of the project.

Possible policy responses to the problems associated with contract incompleteness in this setting are to invest greater effort in pre-construction engineering or to rely more on a design-build framework.[3] The idea behind both alternatives is to reduce the amount of renegotiation that occurs in the construction phase. Renegotiation imposes transaction costs. It also creates opportunities for firms to increase their revenues, generating bid and selection distortions. The welfare gains of improving commitment are recently highlighted in the work of Gagnepain, Ivaldi and Martimort (2013) who study the relative performance of fixed price versus cost plus contracts. Decarolis (2014) finds evidence of a trade-off between low winning prices and poor ex-post performance when commitments on winning bids are not binding.[4]

This paper incorporates contract revisions into a standard bidding model to estimate the effect of modifications on bidder and procurement costs. We investigate highway procurement auctions held in Texas between 2004 to 2011. This procurement environment offers a unique empirical setting to study the impact of contractual incompleteness on costs and test the effectiveness of common practices for two main reasons. First, Texas sharply reduced its budgeted dollars that supported change orders, resulting in a large drop in the amount and number of change orders issued. This shift in management procedures allows us to compare bidding in the same environment but with different contract revision practices in place. Second, Texas is a large state that typically procures 3 to 4 billion dollars in highway construction per year. The data available in this project includes information on nearly 6,300 completed projects that include over 1.8 million bid items let over 8 years. This is a larger and more comprehensive data set than previously examined.

To preview the main results, we find contractors bid less aggressively in auctions with a greater likelihood of modifications, with bidder costs increasing in the level of modifications.

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[3] Crocker and Reynolds (1993) provides an extensive discussion of contract design issues focusing on contractual incompleteness. Arve and Martimort (2015) study optimal procurement contracting with renegotiation and uncertain costs. See also Bajari and Tadelis (2001) for a general discussion of incentives and transactions costs.

[4] Decarolis (2014) considers price renegotiations in procurement of public works in Italy at the time the first price auction format was introduced first. The performance measures considered include cost overruns and time delays. Decarolis and Palumbo (2015) goes a step further, using the same data, to compare extra cost and time delays in renegotiations of fixed price versus design and build contracts.

In the period prior to the reduction in change-order budgets (2004-2006), we estimate that bidder costs were 2.6 to 5.7 percent higher at the mean level of change orders compared to projects with no change orders. These were increases in costs that occurred in addition to the direct costs associated with change orders. In the period when budget restrictions were imposed (2007-2011), we estimate the impact of modifications on bidder costs in the range of 0.0 to 0.7 percent. Given that estimated markups held steady over time, the reduction in contractor costs resulted in a decline in project procurement costs of 2.2 to 6.5 percent.

We also document that the decline in the use of change orders was accompanied by an overall improvement in on-time and on-budget performance for the contracts in our data. The state accomplished these gains holding steady its resources budgeted for pre-engineering and construction management efforts, suggesting enhancements in managerial efficiency were behind the improvements in project performance. Finally, the paper highlights the fact that the incomplete nature of such contracts is not only due to the uncertainty surrounding the characteristics of the underlying projects but also depends on contract management practices. This argues that a more straightforward way to deal with contract incompleteness is improving oversight of the change-order process, as opposed to solutions such as design-build that fundamentally alter the contracting process. This is especially the case in small-to-medium scale projects where design-build contracts may not be feasible.

The remainder of the paper proceeds as follows. The next section discusses the procurement setting and the data employed. Section 3 describes an empirical model of bidding at the project level and Section 4 reports the empirical results from that analysis. Section 5 concludes.

2 The Procurement Environment and Data

All US states operate a Department of Transportation (DOT) that manages road maintenance and highway construction. This includes the management of construction and maintenance projects funded by federal, state and participating local agencies. The typical sequence of events is that a state DOT identifies a set of projects, they design in-house or contract out the design of the projects, assign projects to contractors through an auction process, monitor the work on the project, authorize adjustments to the projects in the field, and make payments to the contractor through completion.

The auction setting is relatively uniform across states. Each state's DOT establishes a bid-letting calendar that identifies the set of projects to be let over the next year or two. Interested contractors may purchase plans for a specific project (referred to as plan holders). Qualified bidders submit sealed bids. Bids are opened at the bid letting and the lowest bid is awarded the contract unless it does not satisfy a number of conditions (discussed below). All states have a flexible reserve rule, which allows the state to reject a low bid if it is a certain percentage above the state's estimate of the cost of the project. The project then is typically re-let at a later date.

Highway construction projects are procured via unit-price auctions. The bid documents include a full list of items and estimated quantity of each item to be installed. This list of items defines the overall work plan for a project. Each bidder submits a unit price on each item along with an overall bid for the project. The estimated quantities are determined by the state's DOT and bidders may not alter the estimated quantities. The overall dollar amount of the bid (or score) is determined by aggregating across all items ($price \times quantity$ estimated). Final payments to the winning contractor may differ from the bid submitted for two broad reasons. First, the actual quantity installed of an item may deviate from the estimated quantity contained in the bid-submission documents. Second, there are contract changes that occur that are not defined by the original set of tasks. These modifications can be thought of as additional or new items that are incorporated into a project post bid-letting. New items can include modifications linked to extra work that alters the scope of construction tasks, adjustments in the nature of existing tasks due to omissions/errors in plans and design, variations due to differing site conditions, and a long list of miscellaneous adjustments to payments.

2.1 Contract Modifications in Texas

As discussed in the introduction, the Texas Department of Transportation (TxDOT) altered its change order practices, lowering the amount of contract resources that it budgeted toward change orders. The motivation was, as a state official told us, to maximize the "pennies on the pavement", increasing the number of projects let at the expense of the change-order budget.[5] The results was that final payments to contracts became much closer to the winning bid over time. In Figure 1, we plot the average ratio between final pay and the winning bid from 2000 through 2011. The plot shows that winners received

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[5] This shift in budget allocation was in response to the tightening of the overall DOT budget in Texas and does not reflect an overall growth in the number of projects let.

about 7 percent higher final payment than their bid in the period 2000 to 2005 but the difference fell to only 2 percent in the period from 2007 through 2011. The shift in change order practices occurred in the 2006-2007 period but was gradual in scope. Change order budgets were reduced. In minutes of a joint meeting of the Association of General Contractors (AGC) and TxDOT, the AGC raises concerns about the lack of funds for change orders. In response, "TXDOT stated they understood the concerns but they currently desire to use the full amount of funds for lettings and not hold funds for change orders."[6]

To characterize the incompleteness of a contract, we propose two alternative measures of modification activity. The first measure is based on the net flow of item-level changes that we observe in the data. It is the overall difference in payments received by a bidder due to contract modifications. To introduce some notation, a project is described by a list of original (o) items $k = 1, ..., G$ and new (n) items $m = G + 1, ..., T$. The quantity for each item k that is estimated by the state is q_k^o. We denote by Δq_k^o the difference between the actual and estimated quantities, namely the under- or over-run. For this term, the unit bid estimate (b_k^{ece}) provided by the state is used to weight the quantity changes. The unit bid estimate is known to bidders prior to the bid letting. For new items, the agreed upon price between the winner and the state is used to construct the value. The index w denotes the winning bidder and q_m^n is the quantity for new item m. The net flow of change orders is then defined for a project a as

$$NCO_a = \sum_{k=1}^{G_a} b_k^{ece} \Delta q_k^o + \sum_{m=G_a+1}^{T_a} b_m^w q_m^n. \tag{1}$$

The net flow variable captures whether overall construction activity is greater or less than the original estimates. Naturally, the variable takes the value zero if there are no under- or over-runs (i.e., $\Delta q_k^o = 0$ for all k) and no new items (i.e., $T_a = G_a$).

The second measure we consider corresponds to the gross flow of contract modifications for a project. For this measure, we aggregate the absolute value of each under-run, each over-run and each new item across all items in a project. The gross flow variable will measure the total value of adjustments that takes place in an auction. It could be the case that the net flow variable is close to zero even for a project with significant modification activity if the value of the under-runs balanced the value of out new items. The gross flow of change orders is constructed as

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[6] Joint AGC/TxDOT Committee Minutes, August 18, 2010.

$$GCO_a = \sum_{k=1}^{G_a} b_k^{ece} |\Delta q_k^o| + \sum_{m=G_a+1}^{T_a} b_m^w q_m^n. \tag{2}$$

Table 1 shows how NCO_a and GCO_a evolve from 2004 through 2011. The variables are normalized by the state's estimate of the engineering cost of the project. The NCO_a variable follows the decline in the final pay variable shown in Figure 1, falling close to zero by 2008. The GCO_a declines by a similar amount in overall magnitude, but there remains a base level of over- and under-run activity that occurs within projects.

The measures of market incompleteness utilized here differ from those used by BHT. BHT disaggregate contract modifications into components due to extra work, a net positive or negative adjustment term, and deductions from the contract. This approach allows for a differential impact on project revenues by source of the change order. Our data do allow a similar, though not identical, disaggregation. However, the challenge this introduces is that it expands the set of instruments required for identification in the estimation stage. In our setting, we will rely on a single instrumental variable which we discuss more fully below and focus on models that use a single composite measure of contract incompleteness.[7]

2.2 Data

To construct the variables in equations (1) and (2) as well as other variables employed in Section 4, we use data that come from the TxDOT's project management data files. There are two main sources of information. The first source is the auction-level information that is available from the bid proposals, bid-letting process, and the payments data.[8] TxDOT holds monthly bid lettings to procure road construction services from private contractors. For each project, the bid proposals and bid-letting documents contain information that describes the project and lists the auction participants. With respect to project details, the key information includes the overall project description, the project location, the state's estimate of overall project costs known as the engineers cost estimate (ECE), the state's estimate of the length of time the project will take in calendar days, and the contact information for the "area engineer" that is responsible for the state's day-to-day management and oversight of the project. The bid-letting data provide a complete list of contractors that purchased plans (both bidders and non-bidders), the dollar value of the bid submitted

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[7] In table A.1, we report how modification activity varies across different types of change orders. The decline observed in Table 2 is widespread across change-order types.

[8] More detail on the construction of the data is provided in the Appendix.

by all bidders, and the identity of the winner (if a winner is chosen). Each contractor has a unique vendor id and business location information. The list of contractors that purchased plans is public information available prior to the bid letting.

For each awarded project, data on payments made to the contractor are also obtained. These data have a dollar amount and the date of payment made to the contractor, along with the start date of the construction project and completion date. The project-level data for all highway construction contracts is available to us from October, 1998 to the end of 2013.

The second source of data is the item-level entries from the bid-letting and payment records. As discussed above, highway construction contracts are awarded in unit-bid auctions. The TxDOT data report the unit bids and the estimated quantities for all individual items listed on a project. Items codes describe detailed tasks and materials to be used – specific grades and depth of asphalt and cement used, the type of rebar installed, the size of trees planted, the type of seed to spread, the type of reflectors and barriers to use, the length of guardrail to be installed, etc. The unit bids are bidder-specific prices for each item, while the estimated quantities are the same for all bidders and set by TxDOT in the planning documents. Bidders cannot alter the estimated quantities even if they believe they are in error. TxDOT also provides contractors with the state's engineering estimate of the price (the unit-bid estimate) for each individual item as part of the bid letting documents.[9] The sum of the state's estimate of costs across all original items equals the ECE of the project. The item detail information from the bid letting is available from October, 1998 to the end of 2013.

For the winner of each auction, the payment data for the complete list of items in a project are also obtained. This includes payments on original items and on any new items introduced in the construction phase of the project. For original items, the TxDOT data report the original quantity, the actual quantity installed, the price of the item, and the total payment.[10] For new items, quantity installed, price and total payment are reported. The difference between the quantity installed and the original quantity for an original item

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[9] While most states provide information on the engineering cost at the project level, many states do not provide state's internal estimate of the costs of the individual items to auction participant either before or even after the bid letting. TxDOT's practice is somewhat unusual in this regard. De Silva, Dunne, Kankanamge, and Kosmopoulou (2009) examines cross state differences in information release at the bid-letting stage and show how differences in information release affect bidding behavior.

[10] Over 98 percent of original items are paid at the submitted price. In the small number of cases where price is renegotiated for an original item, TxDOT includes an additional record with the original item code and the new price.

is the under- or over-run. The final payment received by the contractor is then the sum across all items of the quantity installed times the price of each item. The data on item-level installed quantities and payments are available starting only in 2004 and this limits the empirical analysis to begin in 2004.

A supplementary data set is also available that lists all change orders for a project. A change order is an amendment to the contract issued by the area engineer managing the project. Change orders are reported at the item level but often include changes to more than one item within the same request. The specific change order can introduce new items, delete original items, or alter the quantities for an original item. Besides the quantity and payment detail, information on the reason for the modification is also recorded. Common reasons listed are changes in project scope (extra work), changes due to design errors and omissions, and changes due to differences in site conditions. It is important to note, however, that in many cases under- and over-runs occur that are not detailed on a change order. TxDOT makes clear in its letting documents that the published quantities are only estimates and the actual quantities installed may vary from the original plan. For small or mid-size alterations in quantities installed, a change order may not be issued. Information of change order submission is available beginning in 2002.

Table 2 provides basic sample statistics for the Texas data. Our sample includes information on 6,287 auctions with 30,061 submitted bids for the years 2004 through 2011.[11] The sample is limited to 2011, as only completed projects are used in the analysis. Payment data for 2012-2013 are used only to measure progress on projects let in the latter part of our sample. The sample makes up 97 percent of completed construction projects. The sample contains all types of construction projects including paving, bridge work, and other project types. Projects are placed in one of three broad project groups (paving, bridge, all other) based on the primary set of tasks identified in the item lists, weighted by share in costs.

The average size project and number of bidders per auction is 3.9 million dollars and 4.8 contractors, respectively. The mean number of items per project is 61 and the mean projected number of days of work is 151. Across the period of analysis (2004-2011), there are 1,560 unique plan holders, with 844 firms submitting at least one bid and 508 firms winning at least one auction. A main variable of interest throughout the analysis is the relative bid. The relative bid variable is constructed as the bid divided by the engineering

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[11] A more limited amount of data are available to us prior to 2004 and is used to initialize a set of variables or to create lagged values when needed.

cost estimate of the project. This allows us to compare bids across projects of varying size. The mean relative bid is 1.076 with the mean of the winning relative bid being 0.961.

For each firm in our data set (plan holders, bidders and winners), we construct a set of firm specific variables. To control for differences in firm costs, we construct measures of distance to a project and capacity utilization. For each firm that purchases a plan for a specific project, we calculate the distance of the firm to the project in miles. A capacity utilization variable is constructed in the same fashion as Porter and Zona (1993) taking the ratio of current project backlog to maximum backlog observed for a firm over the period 1998-2013. The early years of data are used to build the firm's backlog series. To control for firm size and bidding experience, a zero-one indicator variable is constructed to identify fringe bidders in the same manner as BHT. A fringe bidder is defined as a bidder who has an overall market share of less than one percent of the market over the entire sample of data 1998-2013.

3 The Bid Model

In this section we describe an empirical model that incorporates contract modifications into a standard bidding model. The approach follows closely the framework presented in BHT and JKLS. Using standard notation but dropping for the time being the index referencing the auction a, the bid submitted for bidder i is

$$B_i = \sum_{k=1}^{G} b_k^i q_k^o, \tag{3}$$

where b_k is the unit price submitted for task k. A bidder's revenue is

$$R_i = \sum_{k=1}^{G} b_k^i q_k^o + \sum_{k=1}^{G} b_k^i \Delta q_k^o + \sum_{m=G+1}^{T} b_m^i q_m^n, \tag{4}$$

where the first term reflects payments received for the original items in the auction, the second term reflects additions or subtractions due to over- and under-runs of the original items and the final term reflects payments for new items. A contractor must form expectations of the over- and under-runs for the original items and an estimate of revenue earned on the new items. In setting up the model, we assume that bidder's are risk neutral and can anticipate the ex-post modifications, the same approach as in BHT. It amounts to assuming that contractors can anticipate modifications that the state engineers do not. This is a strong assumption. In the empirical analysis below, we relax this assumption and allow for error in bidder's expectation of modifications.

The contractors cost is a function of the tasks completed and is defined as

$$C_i = \sum_{k=1}^{G} c_k^i q_k^o + \sum_{k=1}^{G} c_k^i \Delta q_k^o + \sum_{m=G+1}^{T} c_m^i q_m^n. \tag{5}$$

The costs include both the costs of installing the original items, c_k^i, along with the costs associated with contract modifications including original and new items, c_m^i. Realized profit is just the difference between revenue and costs. It is important to emphasize that bidders are compensated for their item specific costs associated with change orders. In the case of new items, if the new item is comparable to an existing item in the contract, the current contract prices are used. If there is no comparable item in the contract, recent winning bid prices are used to price new items.[12] Alternatively, if TxDOT and the contractor cannot come to an agreement on the item price, the contractor will be paid using the force account approach. Force account work pays the contractors a set schedule based on the labor used, the materials and machinery on site. Still, such compensation may not fully account for the types of disruption or adaptation costs discussed in BHT.[13]

Bidder i's expected profit from the project is

$$\pi_i = \left[\sum_{k=1}^{G} b_k^i (q_k^o + \Delta q_k^o) + \sum_{m=G+1}^{T} b_m^i q_m^n - \sum_{k=1}^{G} c_k^i (q_k^o + \Delta q_k^o) - \sum_{m=G+1}^{T} c_m^i q_m^n \right] \cdot (Pr(s^i < s^j), \tag{6}$$

where the first two terms represent payments received on the original and new items, respectively, and the second two terms are the contractors costs for both sets of items. The s^i is the overall bid submitted (or score) in the auction by bidder i, and the last term is the probability that bidder i's bid is the low bid in the auction.

The bidder's problem is to choose a set of unit prices (b_k^i's) for the original items that

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[12] Guide to Contract Change Orders, Fall 2006.

[13] Force account work requires daily records of labor, machinery and materials used that is signed off on by the area engineer and contractor. The contractor reports hours of labor and compensation by type of worker, machinery use and rental rate, and materials use. The state pays 25 percent over the value of invoices received for materials to compensate the contractor for overhead and profit (TxDOT Form 316). The Federal Highway Administration recommends against using force accounts to carry out change orders.

maximize expected profits factoring in the magnitude and nature of expected modifications, subject to the constraint that $s^i = \sum_{k=1}^{G} b_k^i q_k^o$. Define the probability that firm i's bid exceeds firm j's bid as $H_j(s^i) \equiv Pr(s^i > s^j)$ and $\prod_{j \neq i}(1 - H_j(s^i))$ as the probability that firm i wins the auction with a score of s^i. As BHT describe, the bidders problem is solved in two stages. In the first stage, bidders choose the optimal set of unit bids given a score. This generates a bid function based on the score. In the second stage, bidders choose the optimal score using the results from the first stage optimization process.[14] This implies that the derivative of profit (equation 6) with respect to the unit bid for each of the G tasks is zero at the optimal score. Taking the derivate of (6), summing across the G first order conditions, and solving for the bid yields

$$\sum_{k=1}^{G} b_k^i q_k^o = \left(\frac{1}{G}\sum_{k=1}^{G}\frac{(q_k^o + \Delta q_k^o)}{q_k^o}\right)\left(\sum_{j \neq i}\frac{h_j(s^i)}{(1 - H_j(s^i))}\right)^{-1} + \sum_{k=1}^{G} c_k^i q_k^o + \sum_{k=1}^{G}(c_k^i - b_k^i)\Delta q_k^o + \sum_{m=G+1}^{T}(c_m^i - b_m^i) q_m^n. \quad (7)$$

The first order condition shows that the submitted bid (LHS) equals the weighted markup, the costs of original items, a term for net payment over- and under-runs, and the net payments due to new items.[15] This FOC equation says that the bid at the auction level is formulated such that the overall reimbursement by the state ex post will be equal to the weighted markup plus the cost of all items after the renegotiated quantities are taken into account minus the surplus realized through the introduction of new items.

3.1 Unbalanced Bidding

The assumption in writing down the empirical framework above is that bidders can ascertain projects that are likely to have modifications and incorporate this information into their bidding strategy. This raises the issue of whether bidders can also exploit unbal-

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[14] Based on the results in Asker and Cantillon (2008), BHT show that this two-stage model has a unique Bayesian-Nash equilibrium.

[15] This follows closely the expression in BHT and JKLS. BHT expresses the FOC in terms of actual quantities installed (q_k^a) which is just $q_k^o + \Delta q_k^o$. One can rewrite the expression substituting in for the actual quantities installed, collect terms and show that this is identical to the expression in BHT. This would redefine the bid variable as bid submitted on actual quantities used and the cost variable (on right hand side) as costs of actual quantities used.

anced bidding strategies in this setting. Clear evidence of unbalanced bidding would argue the empirical approach described above that treats the change orders as an auction-level attribute is problematic. We assess this issue here.

As discussed above, bidders submit a price for each bid component and the individual components aggregate up to the overall bid submitted by the contractor. The contractor cannot alter the estimated quantities set out in the project documents – even though, the contractor might believe that certain estimated quantities are likely in error. Unbalanced bidding occurs when a contractor believes that there will be over-runs or under-runs on a particular item and submits a price list that incorporates the likelihood of such over- and under-runs in order to increase revenues in the construction phase.[16]

For example, suppose a potential bidder believes that the highway department has underestimated the amount of cement that is required in building a bridge. In such a case, the bidder would submit a relatively high price on the cement component effectively increasing the margin on that item, while lowering the price on other project components in order to compensate for the higher submitted cement price. In the limit, a risk neutral bidder would lower the price on the unadjusted items toward zero and increase the cement price to the maximum amount, given the constraint on the overall bid submitted. By doing so, the bidder would yield higher revenues ex-post than the originally submitted bid for the work. The payoffs to this unbalanced-bidding behavior are illustrated through examples in both BHT and Miller (2014) who show that these payoffs can potentially be large.[17]

To assess whether this is an issue in our setting, we examine if the unit bids submitted can predict the over- or under-runs that occur at the item level. The idea here is that if bidders can anticipate over- and under-runs at the item level, they should submit relatively high unit bids on items expected to over-run and offset this with lower bids on items that may under-run. The regression estimated is

$$\frac{\Delta q_{ka}^{o}}{q_{ka}^{ece}} = \lambda \left(\frac{b_{ka}^{i}}{b_{ka}^{ece}} \right) + \nu_{ka}^{i}, \tag{8}$$

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[16] The Federal Highway Administration has specific regulations guiding the evaluation of unbalanced bidding in federally financed highway construction contracts (23 CFR 635.114 and 23 CFR 635.102). States are required to examine bids for specific irregularities. FHWA may limit its own participation in contracts that fail to meet their guidelines.

[17] Athey and Levin (2001) show that bidders in timber auctions do submit skewed bids which results in higher ex-post profits. The information asymmetry is driven by differences in knowledge about the distribution of tree species in a tract. In our setting, it is the ability of the contractor to identify mistakes and omissions in design plans, to know about current site conditions, or perhaps to aggressively renegotiate contract terms in the construction phase.

where the dependent variable is the relative difference between the actual quantities of an item installed in a project and the estimated quantities. The estimated quantities for each item are produced by the design engineers for the project and these are the quantities used by the contractors in the submission of unit bids. The actual quantities reflects the final installations of each item under the winning contract. The main independent variable (the first term on the right hand side) is the relative unit bid of bidder i in auction a for item k. b_{ka}^{ece} is public information available to all potential bidders prior to the bid letting. This detailed information at the individual item level is not provided by all DOT's, either ex ante or often even ex post, and is an advantage of the Texas data. The key parameter in the equation is λ and it measures the relationship between the relative unit bids submitted by contractors and deviations in actual quantities installed from estimated quantities. If firms are submitting skewed bids to increase revenue, one would expect λ to be positive. If bidders are increasing some bids in an auction while decreasing others in the same auction, one would expect the errors of the model (ν_{ka}^{i}) to be correlated at the bidder-auction level. Therefore, all models will be estimated clustering the standard errors at the bidder-auction level.[18]

The results from the regression analysis are presented in Table 3. The underlying data includes over 1.8 million item-level bids contained in our 6,287 completed auctions. The first column reports the results from a specification using all auctions from 2004-2011. The coefficient on the unit bid term is positive and statistically significant, though very small in magnitude. A relative unit bid of 10 percent above TxDOT's estimate predicts a 0.15 percent over-run. The next two columns break out the sample into the sub-periods 2004-2006 and 2007-2011, allowing for the effects to differ between periods of high and low change-order activity. The estimated coefficients remain very small in the models for the sub-periods.[19]

The item-level regressions suggest that unit bids are weakly correlated with item over- and under-runs. As an additional piece of evidence, we perform an auction-level check and compare the revenue generated by the submitted unit bids to an alternative strategy

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[18] The empirical model is similar to the specification estimated in BHT. The one difference is that Texas data includes the project-specific state's cost estimate for each item, while the California analysis relies on more aggregate price data to estimate the item-level DOT price. Section A.1 in the appendix provides summary statistics on the item-level data. The models were also estimated with item fixed effects and project controls and the results are the same as those reported in Table 3.

[19] The models were also estimated including item-level fixed, year effects and controls for project characteristics. The results were the nearly identical.

where the bidder submits a set of balanced unit bids. Under the proposed balanced-bidding strategy, a bidder uses the distribution of TxDOT's unit-bid estimates as the basis for their bids, adjusting the unit bids for the overall level of bid submission. If a bidder submitted an overall bid that was .98 of the engineer's estimate for the project, the balanced-bidding strategy submits a set of unit bids each discounted from the unit bid estimate by two percent. This preserves the overall level of bid for each contractor, but generates a balanced set of unit bids. We then compare the payments received under this alternative bidding strategy to payments received under the submitted unit bids, using the actual quantities that were installed. If contractors can anticipate quantity changes, one would expect payments received to be systematically higher under the bidders' submitted price lists than under the balanced-bidding price list.

Table 4 presents results of this exercise. The data underlying the table is at the bidder level and represents the difference between the payments earned under the submitted bid and the payments earned under the balanced bid normalized by the submitted bid. The differences are broken out by year across a set of percentiles. The top panel shows the differences at several points in the distribution for all bidders and the bottom panel presents the same information for winners only. At the median and mean, there is basically no difference in the revenues earned under the two calculations and the tails of the distribution are relatively symmetric. The table also shows there is little change in the statistics over time. In the high and low change order periods, the distributions look very similar. The same general patterns hold for the winners-only panel.

The muted relationship between relative unit bids and changes in item-level quantities was also seen in the California study by BHT.[20] Still, in that analysis, a strong relationship between change orders and bidding was found at the auction level. The California results suggest that while bidders can anticipate projects that are likely to require modification, they cannot easily identify the impact of such changes on item-level over- and under-runs. With this in mind, we now turn to a description of the empirical bid-level model.

3.2 Empirical Model

The FOC obtained in equation (7) forms the basis for our estimating models. The key elements we need to model are costs, the markup term, and the role of contract modifications.

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[20] Nystrom (2015) also finds little evidence of unbalanced bidding using Swedish construction project data.

We model bidder costs to complete a project as a combination of auction characteristics and idiosyncratic bidder costs and estimate markups using a standard empirical auction model. Contract modifications are modeled using ex-post realizations from the completed project. In the latter case, we recognize that in the optimization problem bidders would incorporate an expectation of the modifications, as opposed to observing the realization. To address this issue, we treat the issue as a classical errors-in-variable problem and use an instrumental variables approach. The various components are then incorporated into an empirical model that estimates the effect of contract modifications on bidder costs.

3.2.1 Costs

First we need to specify an expression for bidder costs on the original items. At this point, we will begin to distinguish between projects denoted by a. We will assume that bidder i estimated costs for the original items in project a takes the following form:

$$\sum_{k=1}^{G_a} c_k^i q_k^o = cost_a^{ece} \cdot \left(z_a' \beta + \eta_{ia} \right), \tag{9}$$

where η_{ia} reflects bidder specific idiosyncratic cost and is assumed to be identically distributed across bidders and auctions and independently distributed across auctions. In the empirical section, we cluster standard errors allowing for within auction dependence. The expression models bidder costs for project a as a multiplicative function of the state's estimate of the engineering costs.[21] The state's engineering cost estimate controls well for cross-project heterogeneity in costs; however, previous empirical studies have shown that project costs also vary by observable project characteristics (z_a). Project characteristics include the number of items or tasks, the length of the project in days and a set of indicator variables that control for cost shifts associated with the location of project, the type of project, the month of bid letting, and project year.[22] Our strategy here is to include a detailed set of cost control variables to reduce the likelihood that the parameter on the modification term suffers from an omitted variables problem.

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[21] The importance of controlling for cost heterogeneity in this environment is discussed in Krasnokutskaya (2011). A similar multiplicative form without the additional project control variables contained in z_a is used in BHT.

[22] The variable based on the number of tasks has been used as a proxy for project complexity in previous highway procurement studies and project length in days could reflect project scheduling flexibility (Tadelis (2012)).

3.2.2 Markup Estimation

The empirical model requires the estimation of $h_j(s^i)$ and $H_j(s^i)$, components of the markup term in the model, and an estimate of the term that weights the markup. The markup will be estimated in a two-step approach, similar to Haile, Hong, and Shum (2006), De Silva, Dunne, Kosmopoulou and Lamarche (2012) and Bajari, Houghton and Tadelis (2014). The first step estimates a relative bid model that controls for auction and bidder characteristics

$$rbid_{ja} = x'_{ja}\mu + \theta_a + \epsilon_{ja}, \tag{10}$$

where $rbid_{ja}$ is the bid divided by the engineers cost estimate for bidder j in auction a, x_{ja} includes bidder characteristics (distance, capacity utilization, fringe status), θ_a is a set of auction fixed effects, and ϵ_{ja} is the error term.

The second step uses the distribution of the error term, ϵ_{ja}, to model the distribution of bids. Recall that $H_j(s^i) = Pr(s^j < s^i)$. Substituting in the right-hand side of the above regression model, we obtain the probability that bidder i's bid is greater than bidder j's as

$$H_{ja}(b_i) = Pr(x'_{ja}\mu + \theta_a + \epsilon_{ja} \leq s^i_a) \equiv G_N(rbid_{ia} - x'_{ja}\mu - \theta_a), \tag{11}$$

where N indexes the number of bidders in an auction. We allow the distribution of bids to vary by the number of bidders, by project type and across the two policy periods. Under i.i.d. assumptions on the error term ϵ, we estimate equation (10) using standard parametric models, obtain the residuals, $\hat{\epsilon}_{ja}$, and use $\hat{\epsilon}_{ja}$ to estimate the density $\hat{h}_{ja}(s^i)$ and $\hat{H}_{ja}(s^i)$. We obtain $\hat{h}_{ja}$ and $\hat{H}_{ja}$ considering a continuously differentiable kernel function over a compact support and a properly chosen bandwidth. We use a triweight kernel to estimate the density and distribution functions.

In addition to obtaining estimates of $\hat{h}_{ja}$ and $\hat{H}_{ja}$, we also need to model the term that weights the markups. The weighting term, the first variable on the right hand side of equation (8), is auction specific and is

$$w_a = \frac{1}{G_a}\sum_{k=1}^{G_a}\frac{(q^o_k + \Delta q^o_k)}{q^o_k}. \tag{12}$$

This term is the actual quantity of an original item installed divided by the estimated quantity in the plans averaged across all items in an auction. If there are no under- and over-runs on the original items specified in the bid letting documents, the weight is one. We estimate an auxiliary regression using project characteristics, information on the history of changes for the listed items in an auction, and a set of dummy variables that identify the area engineer responsible for the project to predict an estimated weight for each auction, $\hat{w}_a$. This procedure reduces the outliers in the tails of the distribution of the weighting term that are driven by situations where one item (typically a small item in terms of value – e.g., traffic reflectors) in an auction has a very large effect on the average weight.

3.2.3 Contract Modifications

Next we will assume that bidders incorporate their expectations of change orders using one of the measures of contract incompleteness discussed above. The contract modification terms in the FOC encompass the net flow measure of project incompleteness directly and can be parameterized for project a as

$$\sum_{k=1}^{G_a}(c_k^i - b_k^i)\Delta q_k^o + \sum_{m=G_a+1}^{T_a}(c_m^i - b_m^i)q_m^n = (\tau_a - 1)NCO_a. \tag{13}$$

The contract modification term is included as a linear expression and reflects the overall net revenues – the differences between the costs incurred on a project due to modifications and the revenues earned. We assume that costs are linked to the observed modifications. If τ_a equals one, then the impact of modifications of contractor profits would be zero, as contractors would be just compensated for the costs incurred. If τ_a is less than one, contractors revenues exceed costs when modifications occur. This could be the case, for example, if contractors can generally exercise monopoly power during the construction phase when negotiating prices for extra work or for contract changes due to design errors or omissions. If τ_a is greater than one, then costs exceed payments. This is the adaptation cost finding of BHT where bidders adjust up their bids for projects with a high likelihood of modification. Finally, the composite expression is used in place of the individual terms, in part, because we find that the under- and over-runs and new items show a negative correlation in the data[23] We do explore alternative forms of the contract modification

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[23] A small amount of substitution of closely related items occurs in the data. The modification of existing items is discussed in the Guide to Contract Change Orders (2006): "If the proposed change affects only a component of the overall cost of an existing item, then revise the cost only for the affected component. For example, when work involves a change in type of asphalt, establish a new item and revised price based on the change in material cost only." We find 1445 item replacements, where an old item is replaced by a new

variables in the appendix and report on models substituting the variable GCO_a for NCO_a in the empirical results section below.

3.2.4 Model Estimation

Combining the components into the FOC, the estimation equation is then

$$rbid_{ia} - \frac{\hat{w}_a}{cost_a^{ece}} \left(\sum_{j \neq i} \frac{\hat{h}_{aj}(s^i)}{(1 - \hat{H}_{aj}(s^i))} \right)^{-1} = z_a' \beta + \gamma \frac{NCO_a}{cost_a^{ece}} + \eta_{ia}. \tag{14}$$

The estimating equation replaces the markup with an estimated markup and transforms the model into a specification that models the pseudo cost of a bidder normalized by engineer cost estimate, the left-hand side of (14), as a function of the modification variable along with controls for project characteristics. The contract modification term, $(\tau_a - 1)NCO_a$ from (13), is parameterized as γNCO_a. This term reflects the effect on costs that contractors associate with modifications. These costs, factored into bids, are above and beyond the direct costs of the modifications which contractors are compensated for through the change order process.

As mentioned earlier, a key issue is the fact that the contract modification variable is an ex-post realization. BHT note that rather than assuming that bidders have perfect foresight about the actual quantities of original and new items installed, bidders could be viewed as having symmetric uncertainty about the actual quantities. This implies that bidders have common rational expectations with respect to the actual quantities installed.[24] This introduces noise into the bidder's estimate of contract modifications. We address this issue as a measurement error problem. While we observe the ex-post realizations, the variable that bidders would employ is the expectation of modifications. The expected value of modifications is the ex-post realization plus measurement error. We assume that measurement error is i.i.d. and the problem is one of classical measurement error.[25] The solution is to identify instrument(s) correlated with the signal of the expectation of the contract modifications but uncorrelated with the measurement error.

The instrument that we use throughout the analysis is based on information on past change order activity associated with the area engineer overseeing a project. The area engi-

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item within the same class of item codes (5-digit level) and have the same units of measure.

[24] Bajari, Houghton, and Tadelis (2014), page 1293.

[25] Miller (2014) takes a similar approach in estimating a model where bidders form expectations about item-level changes in quantities.

neer is the TxDOT employee that manages the construction project and initiates all change orders. The bid-letting documents identify the area engineer by name and provide contact information, so that contractors know the area engineer associated with each project at the bid-letting stage. For each area engineer overseeing a project, a variable is constructed that measures the average number of change orders per project the area engineer submitted over the prior two years. Similar to BHT, this relies on bidders inferring expected change orders from their knowledge of the area engineer's change order issuance. We utilize a time varying instrument to allow for the fact that change order practices shifted over our period of analysis. The moving average of past change order activity declines steadily over time from a mean of 21.4 on change orders issued in 2004 to 12.3 in 2011.

A number of other instruments were also considered. In particular, past quantity changes at the item level were used to construct an instrument based on the past propensity of items listed in a given auction to be modified. We also allowed interactions between the past experience of a bidder with an area engineer and the instrument. None of these additional instruments or interactions improved the performance of the instrumental variable estimation.

Before going to the results, it is useful to point out the main differences between our estimating model and BHTs. First, our approach includes the over and under-runs in the contract modification variable. This treats all the post-bid letting modifications similarly and does not make the assumption that bidders know the actual quantities installed on the original items at the bid-letting stage. This is also consistent with the findings from the unbalanced bidding analysis that bidders cannot anticipate specific item level over- and under-runs. Second, the model does not include a penalty function to account for the possible losses to bidders when submitting unbalanced bids. Under standard highway contracting procedures, a winning bid may be rejected if it is deemed too unbalanced. BHT found the associated parameter to be both small in magnitude and having the wrong sign.[26] Moreover, in email correspondence with TxDOT, the staff reported to us that they have no record of a recent low bid being rejected because it was deemed unbalanced. Third, the model simplifies the measure of project incompleteness to one variable. BHT uses a vector of modification variables that differ by the type of change order and direction of change. While this is certainly a more flexible modeling choice, we could not pursue this approach successfully because of the single instrument at our disposable. BHT used area engineer

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[26] The penalty term also introduces an additional endogenous variable that would need to be instrumented for in the estimation.

fixed effects but this did not work well in our application, as the area engineer fixed effects failed standard tests of weak instruments (see Table A.2). This is likely related to the fact that change order issuance practices differed markedly over time in our setting with both the mean and variance of change orders declining sharply.

4 Empirical Results

Before proceeding to the main results, Table 5 presents information on the distribution of the markups generated in the first part of the estimation. The table shows the estimated markup relative to the bid at the 10th, 50th and 90th percentiles for the pooled sample, along with the two sub-samples. The magnitude of the estimated markups are quite consistent with the prior literature on highway procurement contracts.[27] These auctions are viewed generally as quite competitive. In addition, markups are slightly higher in the first period as compared to the second period. This pattern reflects to some extent the fact that competition (as measured by average number of bidders per auction) rose toward the end of our sample. This was likely due to the weak performance of the overall economy and state budget pressures that limited the number of lettings. Figure 2 depicts how markups vary by the number of bidders in our auctions. As the number of bidders increase, estimated median markups decline.[28]

The main results from the empirical model are presented in Table 6.[29] The top panel shows estimates from the models that uses NCO_a as the measure of contract modification. The bottom panel presents the estimates from the GCO_a models. For each panel, results are presented across three sample periods and for three specifications. The three specifications differ by the project controls variables included: (1) no additional project controls; (2) a partial set of project controls; and (3) a full set of project controls. The partial set of controls includes year, month of bid letting, construction zones (locations), and project-type dummy variables. The full set of controls augments the models with the number of items and calendar days variables. We alter the specification to assess how sensitive the overall results are to controls for project heterogeneity, that is, to the functional form

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[27] BHT report a median markup of 0.038 for paving contracts in California for 1999 to 2005.

[28] Markups can only be estimated for auctions with two or more bidders. This reduces our estimation sample by 84 auctions that had only one bidder.

[29] Table A.3 in the appendix presents a set of bid regressions that show the correlation between bids and the contract modification variables controlling for bidder and project characteristics. The IV parameter estimates are larger than the OLS estimates, suggesting that attenuation bias is important in this setting.

described in equation (9).

At the bottom of the panels, the partial F-statistics from the first stage of the IV model are presented. Overall, the F-statistics show that the past change order activity of an area engineer is a relatively strong instrument based on the standard Yogo-Stock test statistic for all specifications except for the models that use the NCO_a variable in the 2007-2011 sample. While not shown, the coefficients on the past change orders by an area engineer variable are positive in all the first stage models.

Looking at the results from the second stage of the estimation on bidder costs and contract modifications, there are several findings. The first is that contract modifications are associated with higher bidder costs in the full sample under both definitions of project incompleteness. Contractors bid less aggressively in auctions that are likely to have significant changes in work, reflecting higher estimated project costs. In the 2004-2006 period, the same pattern holds. The coefficients are of similar magnitude compared to the pooled sample but the standard errors are somewhat larger.[30] The estimates for the change order variables in the model with full set of cost controls, however, are no longer statistically significant. In the 2007-2011 period, the contract modification parameters are generally smaller and not statistically significant under both definitions of change orders and across the differing cost-control specifications. A second finding is that the inclusion of project controls has a tendency to reduce the magnitude and statistical significance of the parameters that capture the effect of modification activity on bidder costs, with the number of items as being the prime dampener of the contract modification effects. Prior studies have argued that the number of items in a project is a proxy for project complexity (Tadelis (2012)). It may be the case that such complexity is also correlated with the potential for project incompleteness, with more complicated projects having more room for disruption and renegotiation of tasks. Finally, an increase in the log of calendar days decreases costs and may reflect greater scheduling flexibility for projects that have more contract days, holding project size fixed.

To assess the empirical magnitude of change orders on bidder and procurement costs, Table 7 presents the estimated effect of modifications on bidder and winner costs calculated using the parameters from Table 6 and the means of the NCO_a and GCO_a variables for the three time periods. The top panel shows the estimated magnitudes of the effects for the model that uses NCO_a variable and lower panel reports the corresponding effects from the

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[30] The use of clustered standard errors at the auction level increases the standard errors substantially in our application, especially in the sub-samples.

specification that includes the GCO_a measure. The first three columns present the effects on bidder costs and the last three columns report the effects for winner costs in percentage terms. Not surprisingly, the results show that the effect of contract modifications on bidder and winner costs is larger in the 2004-2006 period compared to the 2007-2011 period. This is due both to the generally larger size of the estimated parameters and higher change-order activity in the 2004-2006 period. In specifications that use the NCO_a variable – our main specification, modifications raise bidder costs by on average 5.7 percent in 2004-2006 in models without project costs controls and a more modest 2.6 percent in models with a full set of project-cost controls. The estimated effects are larger for the models that utilize the GCO_a measure of project incompleteness. The effect on winner costs is estimated to be somewhat larger than the effect on bidder costs, as the average of winner costs is lower than the average of bidder costs. The calculated effects on winner costs reflect the impact of contract revisions on TxDOT's procurement costs and range from 3.1 to 6.7 percent based on the NCO_a specifications.

In the 2007-2011 period, the impact of contract modifications on costs is reduced across all specifications and under both definitions of change orders. It is important to note that even though the gross flow measure maintains a relatively high level of activity in the 2007-2011 (see Table 2), the effect on bidder and winner costs shows a sharp decline in comparison to 2004-2006. This suggests that what is key in terms of the effects of modifications on bidder costs is the activity that results in changes in net payments, as opposed to the standard fluctuations in quantities due to over- and under-runs on original items. Overall, the findings in Table 6 indicate that the decline in the use of change orders reduced procurement costs by 2.2 to 6.5 percent in the NCO_a model, though the differences become smaller and less statistically significant as additional cost controls are included in the models.

4.1 Alternative Measures of Project Performance

One natural question is whether the shift in change order policy was reflected in other measures of project performance, in particular, whether projects finished on time and on budget. If the reductions in the use of change orders reflects a decline in incompleteness in a contract, one might expect that projects finished on schedule and within budget to a greater extent after the change in policy. TxDOT provides such information at a project level. For every completed project, TxDOT reports the number of additional days required to complete a project and the final payments (used in Figure 1). We use the information on additional days to completion to model how project delay varies over time in our sample, controlling for project characteristics. Table 8 reports the results from two alternative empirical models. The model in column (1) presents the results from a regression of the number of additional days on a set project-level controls (size, number of tasks, calendar days, month, zone, project type) and year effects. The model in column (2) reports the results from a probit model where the dependent variable is an indicator that equals one if the project finishes on or ahead of schedule or equals zero if it is delayed. The results in column (1) show that the number of additional days falls sharply over time. The number of additional days is 15.6 less in 2007 compared to 2004, the omitted year effect. To put this in perspective, in 2004 the mean additional days averaged 35.3 days. Moreover, the reduction in the number of days holds steady from 2007 to 2011. The second column reports the marginal effects from the probit model of on-time performance. The probability of a project being completed on time jumps starting in 2007. The probability of on-time performance increased by .13 to .21 probability points over the period 2007 to 2011 compared to the omitted year 2004.

The last column in Table 8 reports the results from a probit model of whether a project was on budget or not. An on-budget project is defined to be one where the final payment does not exceed the winning bid by more than one-half of a percent. The dependent variable is equal to one if the project is on budget, otherwise it is equal to zero. The right-hand side of the model is the same as that reported in column 2. Not surprisingly (given the patterns observed in Figure 1), the results show that the likelihood of a project being completed on budget is much higher in the later years. Overall, the exercises reported in Table 8 suggest that TxDOT's managed projects more effectively post 2007 with projects coming in closer to schedule and on budget compared to projects let prior to 2007.

The TxDOT experience illustrates that contract modifications are not only a feature of the construction environment, but also a choice of the project manager. TxDOT was able to reduce the use of modifications through an explicit change in budgeting and project management practices. One possibility is that this shift in change order issuance might have induced as increase in project engineering and/or construction management costs. To check on this, we obtained information on TxDOT's budgets for pre-engineering and construction management over the period 2004-2011 for the projects in our sample. These data measure the costs TxDOT bears in designing and managing construction projects but do not include the contractors' construction costs. The mean level of pre-engineering costs relative to the ECE in a project did not rise over time, nor did construction management costs (Table 9). This suggest that TxDOT accomplished the reduction in contract modifications and increased on-time performance through gains in managerial efficiency, as opposed to increases in managerial resources.

4.2 Robustness Checks

In addition to the alternative specifications already presented in Table 5, we also performed a set of robustness exercises on the IV models. The first robustness check was to limit the sample to the years 2004-2009. As we document in the appendix, the last two years in the sample do face some attrition because a number of longer and larger projects are not completed by 2013. While 89 percent of projects let in 2010 and 2011 are completed by the end of 2013, only 49 percent of the value of projects let is completed.[31] To assess, whether our results are affected by such right censoring of larger projects in the data, we omitted the last two years from the analysis. Table A.4 in the appendix shows that the coefficients in the pooled sample (2004-2009) and the second period sample (2007-2009) are quite similar quantitatively and qualitatively to those reported in Table 5.

A second issue that we examine is the influence of the truncation of the markups on our estimates of pseudo costs and the results of the structural model. An issue with the first stage markup estimation approach is that it can yield estimates of markups that exceed bids. This implies negative pseudo costs which does not make economic sense. This problem occurs in 0.30 percent of the sample bids. In the above results, we truncated the ratio of the markup-to-bid distribution at 1.00. Table A.5 shows what happens to the coefficients if one either tightens the truncations bounds (to limit markups to 0.5) or relaxes the truncation bounds (to a limit of 2.00). Our results are robust to tightening the truncation point chosen (lower panel of Table A.5). When we allow for negative pseudo-costs, the results are somewhat more muted (upper panel of Table A.5). We rejected the alternative to dropping such observations as these high margin producers disproportionately represent winners in the auctions.

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[31] Our reasoning for keeping projects in the sample in 2010 and 2011 is that we want a longer time period and more post-recession years to assess the effect of the shift in the change-order policy on bidding. In addition, we find only a very weak correlation between our measures of contract modification and project size or calendar day length.

5 Concluding Remarks

The overall interpretation of our main results is that TxDOT's change in contract modification practices produced a decline procurement costs. The findings shown here are in the same spirit as the adaptation cost interpretation in BHT, though somewhat smaller in magnitude. Our results also suggests that a more straightforward way to deal with contract incompleteness is improving oversight of the change-order process, as opposed to solutions such as design-build that fundamentally alter the contracting process. This is especially the case in small-to-medium scale projects where design-build contracts may not be feasible.[32]

Finally, we recognize that our empirical approach is quite stylized. The bidding process is analyzed through a standard independent private values framework, augmenting the model with an auction-level control for change orders. The model assumes that bidders are well informed ex-ante about the likely project modifications that will occur. One way to extend this analysis to more closely match the environment would be to move toward an affiliated values framework that treats the change orders as introducing common value uncertainty into the problem. This is a pathway for future work.

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[32] In highway construction, design-build contracts that team up an external design firm with a highway contractor are typically used for the largest and most complex construction projects. TxDOT did not use such a format for projects let during the period under study here.

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A Appendix

The Appendix provides additional information on the data used, the measurement of specific variables, and some additional analyses.

A.1 Data

Sample Information: Our final sample includes 6,287 completed projects for the period 2004 to 2011. The sample omits maintenance contracts which are fundamentally different, rejected auctions (23 projects) and auctions with incomplete or inaccurate accounting and bid data (64 projects). The data sample only includes completed projects and the data from 2012-2013 are used to measure payments, change order activity and completion for on-going projects let prior to 2012. These projects make up 97 percent of non-maintenance, completed projects let over the 2004-2011 period.

Contractor Location and Distance: For each contractor, we mapped their address into longitudinal and latitude coordinates and use these coordinates when calculating the distance to a project. For the project location, the coordinates of the centroid of the county where the project is listed is used. The distance variable is construction using the vincenty stata code that calculates distances based on geodesic differences between two points. The median distance between the project and the location of a bidder is 105 miles. The mean distance (reported in Table 1) is higher because we have several instances where out-of-state contractors bid on Texas projects.

Capacity Utilization: The backlog variable is constructed using data on the dollar value of projects won, the start date of the project, and the number of calendar days. The variable is defined in a similar way to Porter and Zona (1993). A backlog variable is constructed for each month for all plan holders in the data set. At the start of the panel in 1998, each bidder's backlog is initialized to zero. As projects are won by a bidder, the dollar value of the project is added to the backlog of the bidder in the month of the bid letting. As the project commences, the backlog is worked off by subtracting the incoming data on project payments. The length of the project is constructed using the calendar day variable. The substantial number of years of data available prior to the sample used in our analysis (1998-2003) allows us to initialize the backlog series with over five years of data.

Rival Variables: The rival variables are constructed by taking the minimum distance and the minimum capacity utilization from the other plan holders in an auction. The expected number of bidders (used in Table A.2) is based on past bidding participation patterns for each plan holder in the auction. For each plan holder, a bidder participation variable is constructed as the number of bids submitted divided by the number of plans purchased for all previous auctions. The expected number of bidders for an auction is then the sum across all the listed plan holders of the past participation variable. Bidder participation is updated after each bid letting.

Item Statistics: The item-level data from the bid-letting are available to us from 1998 to 2013. For the auctions in our completed auction sample, there are 382,933 original items listed with an average of 61 items per project. Roughly 32 percent of items under-run including deleted items, 25 percent over-run, and 43 percent have installed quantities equal to the estimated quantities. There are 52,805 new items listed which averages out to 8.4 items per project. The dependent variable in our analysis of unbalanced bidding is the relative item bid. This is the item bid submitted by the contractor divided by the corresponding state's estimate. There is also considerable variation in the relative item bid in the data. The interquartile range goes from .78 to 1.45 with the median at 1.04. The regression sample also excludes lump-sum items (7,342 separate items and 34,684 item-level bids). Lump-sum items have the estimated and installed quantities set equal to one and are primarily associated with set-up or mobilization costs.

Change Order Details: The payments data provides a notation of whether an item was involved in a change order. The TxDOT item-level data contain a code that identifies the reason associated with each change order. There are 53 distinct reason codes in the data that we group into 3 broad categories. New items almost always contain a change order code, while original items, where the final quantity installed deviates from the estimated quantity, may or may not have an associated code. The major categories include extra work or changes in the scope of the project, design errors/omissions and differing site conditions, and all other miscellaneous changes. We observe positive and negative adjustments, except in the extra work component. However, the vast majority of negative adjustments occur in original item under-runs. Table A.1 provides a breakout of items by types of change orders for the 3 time periods. All original items are included in the over- and under-run category. All three categories of change orders fell going from the early period (2004-2006) to the later period (2007-2011). Extra work as a share of the ECE declined from 0.029 to 0.010 and contract modifications due to design and site issues fell from 0.050 to 0.031.

Area Engineers: The instrumental variable approach used in the paper relies on the identity of the area engineer assigned by TxDOT to oversee a project. Area engineers are TxDOT employees and cover specific geographic areas. In our sample, we observe 158 different area engineers working across our 5 construction zones. The area engineer can approve small change orders up to \$50,000 but must obtain approval for larger change orders by the district engineer (up to \$300,000) or TxDOT central office for change orders that exceed \$300,000.

For each project, we know the number of distinct change orders issued by the overseeing area engineer. Data on the number of change orders per project over time is available from 2001 onward. For each engineer at each bid letting date, we identify all projects managed in the prior two years and take the mean number of change orders issued per project. For new area engineers that appear in our data (very few), we use the average value in the construction zone over the prior two year period to initialize the series. The instrumental variable is then the moving average of past change order of the area engineer.

We also explored the use of area engineer dummies as an alternative set of instruments, as in BHT. The advantage is that this would give us a large set of instruments and would allow us to explore a richer set of change-order variables in the model and provide tests of over-identification. Unfortunately, the area engineers dummies are relatively weak instruments in our setting. We estimated the models shown in Table 5 using area engineer fixed effects and all the models failed weak-instruments tests. Table A.2 presents the partial F-statistics from the first stage model using the area engineer dummies as instruments. All the F statistics are below 10 under this alternative IV approach.

A.2 Additional Analysis

While the IV estimation forms the core of our empirical analysis, we also use the FOC to motivate a basic descriptive bid regression to examine the correlation between relative bids and our measures of contract modifications. The regression models relative bids for bidder i in auction a as

$$rbid_{ia} = z_a'\beta + x_{ia}'\alpha + r_{ia}'\theta + \gamma \frac{NCO_a}{cost_a^{ece}} + \eta_{ia}, \tag{15}$$

where z_a represents auction characteristics, x_{ia} represents bidder characteristics and r_{ia} are rival characteristics. The vector z_a includes variables that measure the number of tasks and the length of the project in data and indicator variables for location, project type, month and year effects. The vector x_{ia} contains distance to the project location, the utilization variable, and the fringe status variable. The rival variables, r_{ia}, include the expected number of bidders, the minimum rival distance to the project, and the minimum rival capacity utilization. The last two variables are the traditional set of rival controls in this setting and are proxies for rivals costs.[33] The expected number of bidders is constructed using the history of past participation rates for all plan holders in the auction.

The first two columns of Table A.3 presents the results from the ordinary least squares model for equation (15). In short, the standard variables have the expected signs. The second column replaces NCO_a with the gross flow version of the variable. While the coefficient is smaller, the implied magnitude of the effect at the mean of the GCO_a variable is actually larger. Overall, the OLS results suggest a modest positive correlation between contract modifications and relative bids, with little difference across the two sample periods.

In BHT, they disaggregate contract modifications by the source and by the direction of change. In columns three and four of Table A.3, we include a similar disaggregation based on the type of change order identified in the TxDOT data – extra work, changes due to design or site conditions, miscellaneous changes, and over- and under-runs of original items.[34] The estimated parameters on disaggregated modifications variables are very similar in magnitude to those reported in the first two columns. There are some differences in the parameter estimates across the categories but the differences are not large, especially under the net definition reported in column 3. In column 4, greater differences in parameters emerge but it is important to note that most of the gross flow of change order activity will be captured in the over and under-run term as opposed to the terms related to specific change order types. Indeed, the means of the individual gross flow components are small in comparison to the gross over- and under-run term. One reading of the results suggests that adjustments to bids may be more linked to new items, as opposed to over- and under-runs. This is consistent with the discussion of the main IV results in the paper. The last four columns of table A.2 show the same models with project random effects. The results are very similar to the models without random effects presented in columns (1)-(4).

Robustness Exercises: Two sets of robustness exercises on the structural model were also carried out. The first exercise restricts the data samples up through 2009 and replicates the models reported in Table 5 in the paper. This is done to check whether our results are sensitive to sample censoring due to analysis of only completed projects. Table A.4 reports the results. Overall, our results are quite robust to the dropping of the two years of data.

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[33] See Hendricks, Pinske, and Porter (2003).

[34] We also estimated the pseudo-cost IV model using this breakdown of change order variables. In this case, we used the area engineer dummies as instruments but like that reported in Table A.2, the area engineer fixed effects served as weak instruments.

The coefficients estimates on the modification variables from the pooled sample are similar in magnitude and statistical significance to those reported in the paper, and none of the coefficients on the modifications variables estimated using the 2007-2009 are statistically significant at the 5 percent level. The second exercise alters the truncation point of the markups used in the construction of pseudo cost. In the first specification, we relax the truncation to twice the markup, effectively allowing negative pseudo costs for 56 cases. In the second specification, we tighten the truncation point further and truncate markups at 50 percent. This affects an additional 114 observations, increasing the number of truncated observations to 215. The results of the changes in the truncation points are shown in Table A.5. The table presents the results from the specification with the full set of controls, but we have also estimated the models with no controls and the partial set of controls. When one loosens the truncation points, allowing for negative pseudo costs, the coefficients are not statistically significant but the overall pattern remains similar. When we tighten the truncation point (the second panel), the coefficients and statistical significance remain close to those presented in Table 5.

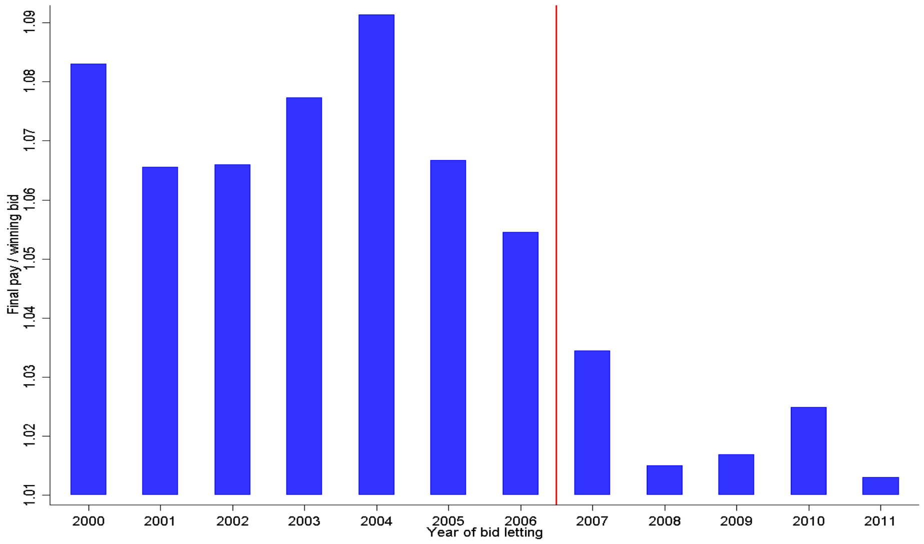

Figure 1: Final pay relative to winning bid

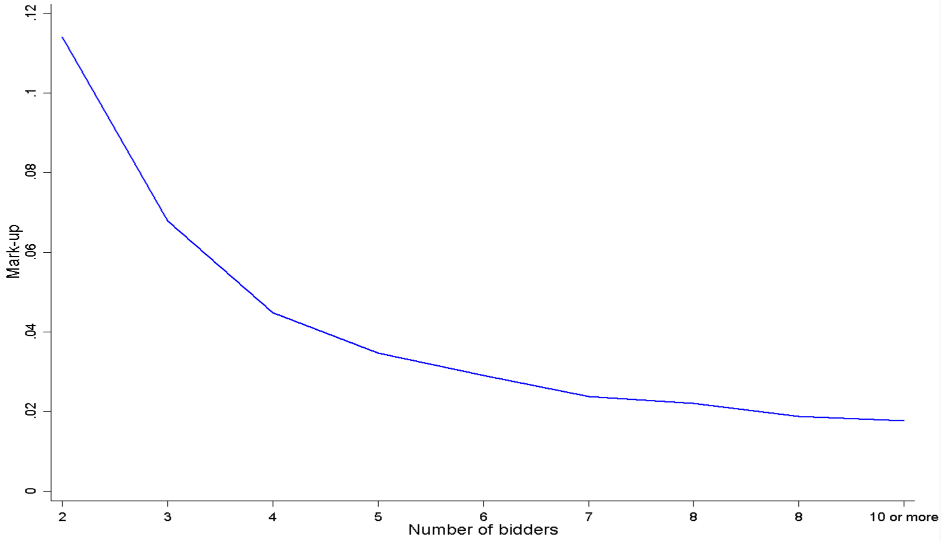

Figure 2: Median mark-ups

Table 1: Average net and gross change orders by year

Year	Number of projects	Net change orders	Gross change orders
2004	861	0.085	0.304
		(0.195)	(0.346)
2005	916	0.065	0.294
		(0.171)	(0.345)
2006	918	0.053	0.257
		(0.124)	(0.272)
2007	742	0.026	0.223
		(0.111)	(0.237)
2008	526	0.012	0.220
		(0.130)	(0.287)
2009	785	-0.001	0.225
		(0.118)	(0.288)
2010	881	0.015	0.208
		(0.130)	(0.264)
2011	658	0.008	0.225
		(0.117)	(0.296)
Total	6,287	0.036	0.247
		(0.145)	(0.298)

Standard deviation are in parentheses.

Table 2: Bidder and auction level summary statistics

Variables	Mean / count	Standard deviation
Auction characteristics		
Number of completed projects	6,287	
Number of paving projects	2,531	
Number of bridge projects	1,642	
Number of other projects	2,114	
Number of bids	30,061	
Number of items for all bidders	1,863,530	
Number of items for winner	382,933	
Average engineer's cost estimate (in millions of $)	3.905	10.802
Average number of plan holders	8.090	3.917
Average number of bidders	4.781	2.485
Average number of days to complete a project	151.296	154.228
Average number of items per project	60.982	56.053
Bidder characteristics		
Average relative bid	1.075	0.245
Average relative winning bid	0.961	0.187
Average distance to a project location (in miles)	205.057	295.111
Average capacity utilized	0.281	0.266
Fringe bidder status	0.773	0.419

Table 3: Relative item bids

Variables	$\Delta q_{jk}^{o}/q_{jk}^{o}$					
	2004 – 2011		2004 – 2006	2007 – 2011	2004 – 2006	2007 – 2011
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta p_{jk}^{o}/p_{jk}^{o}$	0.01555***	0.01545***	-0.00026	0.02198***	-0.00035	0.02198***
	(0.00385)	(0.00387)	(0.00054)	(0.00440)	(0.00062)	(0.00440)
Year effetcs	No	Yes	No	No	Yes	Yes
Observations	1,828,846	1,828,846	705,951	1,122,895	705,951	1,122,895
R^2	0.00000	0.00002	0.00000	0.00073	0.00001	0.00074

Robust standard errors clustered by auctions are in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 4: Actual vs. balanced bid difference

Panel A: All bids							
Year	N	Mean	0.10	0.25	0.50	0.75	0.90
2004	3,711	0.001	-0.034	-0.009	0.002	0.015	0.039
2005	3,440	0.006	-0.030	-0.008	0.002	0.018	0.052
2006	3,429	0.006	-0.029	-0.007	0.002	0.016	0.047
2007	3,256	0.001	-0.027	-0.009	0.001	0.014	0.038
2008	2,872	-0.001	-0.030	-0.009	0.000	0.011	0.032
2009	5,329	-0.002	-0.035	-0.010	0.001	0.011	0.032
2010	4,801	-0.004	-0.031	-0.009	0.000	0.010	0.029
2011	3,223	-0.006	-0.036	-0.010	0.000	-0.011	0.034
Total	30,061	-0.000	-0.032	-0.009	0.001	0.013	0.037
Panel B: Winning bids							
2004	861	0.001	-0.035	-0.008	0.002	0.017	0.040
2005	916	0.001	-0.028	-0.007	0.002	0.017	0.048
2006	918	0.004	-0.029	-0.007	0.002	0.015	0.048
2007	742	0.003	-0.027	-0.008	0.002	0.015	0.041
2008	526	-0.009	-0.031	-0.010	-0.000	0.011	0.031
2009	785	-0.006	-0.036	-0.011	0.000	0.012	0.035
2010	881	-0.002	-0.028	-0.009	0.001	0.013	0.032
2011	658	-0.008	-0.038	-0.011	0.000	0.013	0.038
Total	6,287	-0.001	-0.030	-0.009	0.001	0.014	0.039

Table 5: Estimated bidder mark-ups

Regression sample	Mark-up		
	Percentiles		
	0.10	0.50	0.90
	(1)	(2)	(3)
2004 – 2011	0.017	0.033	0.078
2004 – 2006	0.023	0.042	0.099
2007 – 2011	0.015	0.030	0.065

Table 6: IV estimation results

Variables	Relative pseudo cost								
	2004 – 2011			2004 – 2006			2007 – 2011		
	Project controls			Project controls			Project controls		
	None	Partial	Full	None	Partial	Full	None	Partial	Full
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Net change orders	0.769***	0.741**	0.553*	0.950***	0.729**	0.434	0.123	0.667	0.653
	(0.225)	(0.294)	(0.290)	(0.354)	(0.346)	(0.324)	(0.521)	(0.541)	(0.589)
Log of number of items			0.034***			0.047***			0.025***
			(0.005)			(0.008)			(0.007)
Log of number of days to complete the project			-0.023***			-0.021***			-0.025***
			(0.005)			(0.008)			(0.006)
Project type, zone, month and year effects	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	29,877	29,877	29,877	10,452	10,452	10,452	19,425	19,425	19,425
F-statistics for weak identification	46.160‡	23.510‡	21.370‡	18.190‡	13.180†	12.730†	11.010†	9.895†	7.835
Gross change orders	0.231***	0.167***	0.125**	0.328***	0.232**	0.146	0.021	0.099	0.091
	(0.065)	(0.062)	(0.063)	(0.111)	(0.101)	(0.107)	(0.089)	(0.078)	(0.079)
Log of number of items			0.039***			0.047***			0.032***
			(0.005)			(0.008)			(0.006)
Log of number of days to complete the project			-0.030***			-0.027***			-0.030***
			(0.005)			(0.007)			(0.006)
Project type, zone, month and year effects	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	29,877	29,877	29,877	10,452	10,452	10,452	19,425	19,425	19,425
F-statistics for weak identification	108.800‡	100.100‡	85.420‡	37.490‡	35.070‡	28.370‡	59.800‡	71.280‡	61.720‡

Robust standard errors clustered at auction level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. ‡Denotes >10% and †denotes >15%. F-test values for Stock-Yogo weak ID test. Project specific net (and gross) change orders are instrumented with past change order activity associated with the area engineer overseeing the project.

Table 7: Contract modification effects on costs

Regression sample	Contract modification effects on costs (in %)					
	Bidder cost			Winner cost		
	Project controls			Project controls		
	None	Partial	Full	None	Partial	Full
	(1)	(2)	(3)	(4)	(5)	(6)
Net change orders						
2004 – 2011	2.2	2.1	1.6	3.0	2.9	2.2
2004 – 2006	5.7	4.4	2.6	6.7	5.2	3.1
2007 – 2011	0.1	0.7	0.7	0.2	0.9	0.9
p-value	0.003	0.059	0.337	0.003	0.067	0.361
Gross change orders						
2004 – 2011	5.4	3.7	2.9	6.3	4.5	3.4
2004 – 2006	8.7	6.2	3.9	9.8	6.9	4.3
2007 – 2011	0.4	2.1	1.9	0.5	2.5	2.3
p-value	0.012	0.192	0.556	0.014	0.211	0.582

Average effect is calculated using the relevant coefficient in Table 5 multiplied by the mean of contract modification variable and nomalized by the relative pseudo cost. p-values presented are the tests for the difference in estimates for 2004-2006 and 2007-2011.

Table 8: Alternative project performance metrics

Variables	Additional days to complete a project	Probability of on-time completion[a]	Probability of being on-budget[a]
	(1)	(2)	(3)
Engineer's cost estimate (in $ millions)	-0.07611	-0.00020	0.00228**
	(0.15087)	(0.00137)	(0.00097)
Number of items	0.32880***	-0.00327***	-0.00100***
	(0.03089)	(0.00023)	(0.00020)
Number of days to complete the project	0.01135	0.00037***	-0.00009
	(0.00961)	(0.00008)	(0.00007)
Year			
2005	-3.62915	0.02442	0.04327*
	(2.60407)	(0.02492)	(0.02480)
2006	-7.66777***	0.04508*	0.06301**
	(2.46829)	(0.02484)	(0.02489)
2007	-15.60138***	0.13244***	0.12766***
	(2.50790)	(0.02509)	(0.02620)
2008	-17.17998***	0.18830***	0.22718***
	(2.38472)	(0.02619)	(0.02782)
2009	-15.07466***	0.14336***	0.23007***
	(2.28673)	(0.02481)	(0.02507)
2010	-16.42351***	0.21346***	0.18961***
	(2.09566)	(0.02282)	(0.02482)
2011	-18.39608***	0.20602***	0.21690***
	(1.93363)	(0.02440)	(0.02642)
Project type, zone, and month effects	Yes	Yes	Yes
Observations	6,287	6,287	6,287
R^2	0.20617	0.08480	0.03780
Wald χ^2		569.10000	307.36000

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. [a] Marginal effects from probit models are reported in columns 2 and 3.

Table 9: Pre-engineering and construction management costs

Variables	Sample		
	2004-2011	2004-2006	2007-2011
Pre-engineering estimate	0.067	0.067	0.067
	(0.061)	(0.060)	(0.062)
Construction engineering estimate	0.080	0.080	0.081
	(0.058)	(0.057)	(0.059)

Standard deviation are in parentheses.

Table A.1: Summary statistics by change order types

Variables	2004-2011	2004-2006	2007-2011
Extra work	0.018	0.029	0.010
	(0.068)	(0.090)	(0.043)
Net design and site work	0.039	0.050	0.031
	(0.105)	(0.124)	(0.087)
Net miscellaneous work	0.017	0.019	0.015
	(0.065)	(0.069)	(0.062)
Net over- and under-runs	-0.042	-0.033	-0.049
	(0.155)	(0.163)	(0.150)
Gross design and site work	0.039	0.050	0.031
	(0.105)	(0.124)	(0.087)
Gross miscellaneous work	0.018	0.021	0.016
	(0.066)	(0.070)	(0.063)
Gross over- and under-runs	0.169	0.184	0.159
	(0.178)	(0.182)	(0.174)

Standard deviations are in parentheses.

Table A.2: F statistics for weak identification

Regression sample	Change orders	
	Net	Gross
	(1)	(2)
2004 – 2011	2.883	5.989
2004 – 2006	2.514	4.539
2007 – 2011	8.687	4.938

Table A.3: Regression results for relative bids with net and gross change orders

Variables	Relative bid							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Net change orders	0.131***				0.133***			
	(0.022)				(0.020)			
Gross change orders		0.048***				0.050***		
		(0.010)				(0.009)		
Extra work			0.097**	0.090**			0.110***	0.101***
			(0.038)	(0.039)			(0.034)	(0.036)
Net design and site work			0.166***				0.168***	
			(0.032)				(0.029)	
Net miscellaneous work			0.223***				0.218***	
			(0.057)				(0.057)	
Net over- and under-runs			0.081***				0.079***	
			(0.022)				(0.020)	
Gross design and site work				0.134***				0.136***
				(0.032)				(0.029)
Gross miscellaneous work				0.183***				0.169***
				(0.056)				(0.056)
Gross over- and under-runs				-0.019				-0.016
				(0.020)				(0.019)
Log of distance to the project location	0.008***	0.009***	0.009***	0.009***	0.012***	0.012***	0.012***	0.012***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log of closest rival's distance to the project location	-0.006***	-0.006***	-0.006***	-0.007***	-0.006***	-0.006***	-0.006***	-0.006***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Capacity utilized	0.021***	0.022***	0.020***	0.020***	0.020***	0.020***	0.019***	0.019***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.004)	(0.004)	(0.004)	(0.004)
Rivals minimum capacity utilized	0.024	0.017	0.014	0.011	0.026	0.022	0.020	0.018
	(0.025)	(0.025)	(0.025)	(0.025)	(0.022)	(0.022)	(0.022)	(0.022)
Fringe bidder	0.019***	0.020***	0.020***	0.021***	0.010***	0.010***	0.010***	0.010***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Expected number of bidders	-0.006***	-0.006***	-0.006***	-0.007***	-0.006***	-0.006***	-0.006***	-0.006***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log number of items	0.040***	0.042***	0.040***	0.041***	0.040***	0.040***	0.040***	0.040***
	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.005)
Log of number of days to complete the project	-0.028***	-0.031***	-0.029***	-0.029***	-0.028***	-0.030***	-0.029***	-0.029***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Random effects					Yes	Yes	Yes	Yes
Observations	30,061	30,061	30,061	30,061	30,061	30,061	30,061	30,061
R^2	0.129	0.127	0.130	0.129				

Robust standard errors clustered at project level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. All models include zone, project type, month, and year effects.

Table A.4: Sensitivity analysis of the IV estimation results

Variables	Relative pseudo cost			
	2004-2009		2007-2009	
	(1)	(2)	(3)	(4)
Net change orders	0.509*		0.521	
	(0.294)		(0.664)	
Gross change orders		0.141*		0.101
		(0.080)		(0.128)
Project type, zone, month and year effects	Yes	Yes	Yes	Yes
Observations	21,876	21,876	11,424	11,424
F-statistics for weak identification	19.130‡	54.700‡	9.048	27.190‡

Robust standard errors clustered at project level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. ‡Denotes >10% and †denotes >15% F-test values for Stock-Yogo weak ID test. All models include number of items and calendar days in addition to project type, zone, month, and year effects.

Table A.5: IV estimation results with varying truncation points

Variables	Relative pseudo cost					
	2004-2011		2004-2006		2007-2011	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: limits markup to 2×bid						
Net change orders	0.423		0.231		0.665	
	(0.306)		(0.355)		(0.607)	
Gross change orders		0.095		0.078		0.092
		(0.068)		(0.119)		(0.081)
Observations	29,877	29,877	10,452	10,452	19,425	19,425
F statistics for weak identification	21.370‡	85.420‡	12.730†	28.370‡	7.835	61.720‡
Panel B: limits markup to 0.5×bid						
Net change orders	0.616**		0.542*		0.628	
	(0.289)		(0.322)		(0.580)	
Gross change orders		0.139**		0.182*		0.087
		(0.062)		(0.104)		(0.078)
Observations	29,877	29,877	10,452	10,452	19,425	19,425
F-statistics for weak identification	21.370‡	85.420‡	12.730	28.370‡	7.835†	61.720‡

Robust standard errors clustered at project level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$ ‡Denotes >10% and †denotes >15% F-test values for Stock-Yogo weak ID test. All models include number of items and calendar days in addition to project type, zone, month, and year effects.