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Project Modifications and Bidding in Highway Procurement Auctions

Dakshina G. De Silva, Timothy Dunne,
Georgia Kosmopoulou, and Carlos Lamarche

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Abstract: This paper examines bidding behavior in a setting where post-bid-letting project modifications occur. These modifications change both the costs and payouts to the winning contractor, making the contract incomplete. Recent empirical research shows that bidders incorporate the likelihood of such changes in contracts into their bidding strategies. In particular, contractors may adjust bids to compensate for renegotiation, resequencing of tasks, and other costs associated with project modifications. This paper extends this literature by examining bidding behavior and project modifications in Texas, where there has been a significant shift in change order policy. Specifically, Texas sharply reduced its spending on change orders starting in the mid-2000s. In the period before the change in policy, we estimate that project modifications raised bidder costs by 4 percent to 6 percent. In the period after the change in policy, the impact of project modifications on bidder costs is estimated to be closer to 1 percent.

JEL classification: D4, L1, L2

Key words: procurement auctions, incomplete contracts

Please address questions regarding content to Dakshina G. De Silva, Department of Economics, Lancaster University, d.desilva@lancaster.ac.uk; Timothy Dunne, Research Department, Federal Reserve Bank of Atlanta, tim.dunne@atl.frb.org; Georgia Kosmopoulou, University of Oklahoma and National Science Foundation, georgiak@ou.edu; or Carlos Lamarche, Department of Economics, University of Kentucky, clamarche@uky.edu.

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 incomplete by nature, as the design and specifications may not be fully defined by the construction plans and bid letting documents. Site conditions vary from the original descriptions, the quantities of materials employed can deviate from the initial estimates, and the procurement agency can add extra tasks as required to complete the project or even change the scope of the project. The potential for post-bid letting modifications in project plans is well-known to bidders in these auctions and should be incorporated into bidding behavior. Indeed, state highway administrations are explicit in their concern that bidders can utilize features of the bidding environment to exploit post-bid letting modifications in order to raise profits in the construction phase.[1]

Recent research has found that bidders incorporate the likelihood of project 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. The empirical results indicate that bidders substantially increase their bids in response to the likelihood that project modifications will occur. The authors interpret their main findings as evidence that significant adaptation costs must be incurred when projects are modified post bid letting.[2] The empirical magnitudes of these estimated adaptation costs are large – 8 to 14 percent of the winning bid – similar in magnitude to the standard estimates of the winner's markup in this setting.

Jung, Kosmopoulou, Lamarche and Sicotte (2014) (hereafter JKLS) examine construction projects using Vermont bid-letting data. The focus in this paper is on estimating 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

[1] 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. We discuss unbalanced bidding more fully in Section 4.

[2] It is important to note that these types of adaptation costs are distinct from the construction costs of the project.

of the project due to differences in relative efficiency. Possible policy responses are to invest greater effort in pre-construction engineering or to rely more on a design-build frameworks. The idea behind both alternatives is to reduce the level of project modification that occurs in the construction phase. Crocker and Reynolds (1993) provides an extensive discussion of contract design issues focusing on contractual incompleteness.[3]

This paper extends the literature by examining the role of project modifications and change orders in highway procurement auctions held in Texas over the period 2004 to 2011. Texas is a particularly interesting setting for several reasons. First, Texas in 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 over 8 years. This is a larger and more comprehensive data set than previously examined. Second, Texas explicitly altered its approach to change orders and project modifications during the decade. Specifically, Texas sharply reduced its budgeted dollars that supported 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.[4] The program shift was successful in reducing expenditures associated with project modifications over the decade. This change in program structure will allow us to compare bidding in the same overall setting but with different change-order policies in place.

The main questions asked are twofold. First, do bidder's strategically alter the structure of their bids to exploit post bid changes in the project? Highway construction auctions utilize a unit bid approach, where bidders submit individual prices for each task of the project. The environment allows for the potential to submit unbalanced or skewed bids in order to increase profits. In this situation, bidders increase the submitted unit bids on items they expect to over-run and adjust other item prices downward, resulting in higher revenues at the construction phase and the potential to create inefficiencies.[5] Second, do contractors bid more or less aggressively at the project level where modifications are more likely? Theory argues that bidders should anticipate change orders as the basic structure of the contract is incomplete; however, the specific impact on submitted bids

[3]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]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.

[5]Athey and Levin (2001) examine skewed bidding in timber auctions and Agarwal, Athey and Yang model skewed bidding in on-line advertising auctions. See also Ewerhart and Fieseler (2003) for a related discussion.

depends on the expected profitability of the change orders. Answers to these questions are of interest both from a policy perspective and to the empirical auction literature. From a policy perspective, administrators of road highway programs are explicitly concerned about the use of unbalanced bids in the auction setting as this has the potential to directly raise project costs to the state. Moreover, if change orders increase adaptation costs and bidders alter their bidding strategy in response, as suggested by BHT, then highway administrators should be factoring in such costs in the design and management of projects. From the perspective of the empirical auction literature, there has been a large body of work using highway construction bid-letting data.[6] The work by BHT using California auctions argues that these bid models are essentially mis-specified as the models do not incorporate the potential post-bid letting modifications that end up affecting bidder costs. The analysis of the Texas data will shed additional light on both these issues.

To preview our results, our analysis of the unit bids indicates that bidders are not able to systematically increase project revenues through the submission of skewed or unbalanced bids in Texas. The item-level analysis shows little correlation between unit bids and under- and over-runs – an indication of bidders inability to exploit this particular feature of the auction environment. At the project level, however, we do see the contractors factor in the likelihood of project modifications at the bid stage. Bidders bid less aggressively in auctions with a greater likelihood of project modifications and our estimates of project costs increase with the level of project modifications. In the period before the policy change (2004-2006), we estimate that project costs are about 4 to 6 percent higher at the mean level of change orders compared to projects with no change orders. While smaller in magnitude than the effect reported in BHT, it still reflects a sizable impact on bidder costs. In the period when restrictions are imposed (2007-2011), we estimate the impact of project modifications on bidders costs to be much smaller, in the neighborhood of one percent. A corollary to the analysis in the paper is the magnitude of project modifications is not simply a characteristic of the underlying project but is also a choice that DOTs make. By reducing the use of project modifications, the state reduced procurement costs.

The remainder of the paper proceeds as follows. The next section describes the procurement environment for highway construction projects. Section 3 provides an overview of the data. Section 4 presents an analysis of unbalanced bidding. Section 5 describes an

[6] There is a large literature that does not take into account project 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, Lamarche and Kosmopoulou (2009).

empirical model of bidding at the project level and Section 6 reports the empirical results from that analysis. Section 7 concludes.

2 The Procurement Environment

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 low 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 engineer's estimate of the project. The project then is typically re-let at a later date. Post-bid letting the DOT monitors the progress and quality on a project and makes payments to the contractor.

Highway construction projects are a type of unit-bid auction. 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 project modifications that occur that are not defined by the original set of tasks. These project modifications can be thought of as additional or new items that are incorporated into a project post bid-letting. New items include all other modifications to the contract and can include new tasks; adjustments in the nature of existing tasks due to changes/errors in plans and design; adjustments due to variations in site conditions; bonuses and penalties received during the completion of the project; changes to lump-sum payments; and a long list of miscellaneous modifications. Project modifications that change the nature or scope of work or result from errors/omissions in plans are usually detailed in specific change orders authorized by the DOT. Smaller changes that simply result in over- and under-runs of items may not require an explicit change order.

2.1 Project Modifications in Texas

As mentioned in the introduction, the Texas Department of Transportation (TxDOT) altered its change order policies, explicitly lowering the amount that it budgeted toward change orders starting roughly in 2006. 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 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 drop occurred over several years but was noted by the Association for General Contractors in Texas in 2010 as a problem for contractors as the state construction engineers were "reluctant to execute needed changes and resolve issues."[7]

One way to characterize project modifications in our data is to look at the introduction of new items within an auction. New items are tasks that were not part of the original list of items specified in the construction plans at the bid letting stage. The introduction of a new item on a project is almost always associated with a specific change order. New items are typically introduced to correct for design and omissions in the original plans, to expand the scope of work, or to substitute for original items. Figure 2 plots the average share of new items in a contract from 2004 through 2011, normalized by the TxDOT's estimate of the overall cost of the project. In aggregate, the share of new items declined by about 5 percentage points from 2004 to 2011. The majority of the observed decline in change orders is due to reductions in expenditures on extra work components and project modifications associated with design/site adjustments.[8]

[7] Joint AGC/TxDOT Committee Meetings, August 20, 2010.

[8] While not shown, original items in our data under-run, on average, by 4 to 5 percent. This net under-running is due primarily to deleted items, some of which end up being replaced by new items in the change-order process.

3 Data

The data used in this paper come from the Texas Department of Transportation. 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.[9] 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 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. This data has 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 projects is available to us from October, 1998 to the end of 2013.

The second source of data are 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 very detailed tasks or materials to be used – specific grades of asphalt and cement, the type of rebar, the size of trees to be 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 (unit bid estimate) for each individual item as part of the bid letting documents.[10] The sum of the

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

[10]While most states provide information on the engineering cost at the project level, many states do not

costs across items equals the ECE of the project. These data on item detail from the bid letting is available from 1999-2013.

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.[11] 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 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.

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.[12] Change orders are reported at the item level but often include changes to more than one item within the same change order. The specific change order can introduce new items, delete original items, or alter the quantities for an original item. Besides the quantity and payment information, information on the reason for the modification is also given. 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 plan. For small or mid-size alterations in quantities installed, a change order may not be issued. The data item-level payments are available starting only in 2004.

Table 1 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.[13]

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.

[11] 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.

[12] A change order of less than \$50,000 can be approved by the Area engineer (i.e., the local engineer) that has been assigned to monitor the project. Change-orders between \$50,000 and \$300,000 must be approved by a District engineer. In Texas, there are 25 Districts, organized into five broad constructions zones. Finally, change orders that exceed \$300,000 need approval by TXDOT's Construction Engineer (central management) in Austin, TX.

[13] A more limited amount of data are available to us prior to 2004 and is used to initialize a set of variables

Payment data for 2012-2013 are used to measure progress on projects let in the latter part of our sample and only completed projects are used in the analysis. The sample makes up over 98 percent of completed construction projects. The sample includes all types of construction projects including paving, bridge work, and other project types. Projects are placed in one of there 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 is 3.9 million dollars and the average number of bidders per auction is 4.8. 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, 844 firms that submit at least one bid, and 508 firms than win 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 cost estimate of the project. This allows us to compare bids across projects of varying size. In our sample, the mean relative bid is 1.076 and the mean winning relative bid averaged 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 1 percent of the market over the entire sample of data 1998-2013.

3.1 Measuring Contract Incompleteness

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 project 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

or to create lagged values when needed.

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. i denotes a bidder. The net flow measure is then defined for an auction a as

$$netflow_a = \sum_{k=1}^{G_a}(b_k^{ece}\Delta q_k^o) + \sum_{m=G_a+1}^{T_a}(b_m^i q_m^n) \tag{1}$$

The net flow variable captures whether overall construction activity is greater or less than the original estimates. This net measure is a proxy for how final payments change in response to project modifications. For the auctions in our sample, there are 382,933 original items listed with an average of 61 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 per project.

The second measure we consider is the corresponding gross flow of change order activity based on new items and on under- and over-runs. For this measure, we aggregate across all items in an auction the absolute value of each under-run, each over-run and each new item. The flow variable will measure the total value of adjustments that take place in an auction and distinguishes between projects that have high change order activity and auctions with low change order activity. It could be the case in our data that the net flow variable was close to zero even for a project with significant change orders if the under-runs balanced out new items. The gross flow variable will pick up this type of activity. Thus, this variable might better capture the potential for project disruption and the associated adaptation costs. The gross flow variable is constructed as

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

Both variables measure different aspects of the incompleteness of the original contract. Table 2 shows how $netflow_a$ and $grossflow_a$ change over time from 2004 through 2011. The variables are normalized by project size by dividing each measure by the state's estimate of the engineering cost (ECE) of the project. The $netflow_a$ variable follows the decline in the final pay variable shown in Figure 1, falling close to zero by 2008. The $grossflow_a$ declines by a similar amount in overall magnitude, but there remains a base level of over- and under-run activity that occurs within projects. This is to be expected as the TxDOT makes clear in the bid letting documents that the estimated quantities are only estimates and actual quantities can and do deviate from plan. These deviations will be picked up in the gross flow measure of project modifications.

In the analysis that follows, we examine how bidding relates to these measures of project incompleteness. However, before turning to this analysis, the issue of unbalanced bidding is examined.

4 Unbalanced Bidding in Unit Bid Auctions

The unit bid structure of highway construction contracts allows for the submission of unbalanced bids to increase post-bid letting profits. 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.

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) but potentially they could be large.[14]

[14] Athey and Levin (2001) show that bidders in timber auctions do submit skewed bids which results in higher profits ex post. 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

There are clear incentives for firms to submit unbalanced bids in this environment and highway administrators understand that project costs may be negatively affected by such bid submissions. In response, state department of transportations including Texas' review submitted bids and, in particular, the submitted low bid for unbalanced bidding. Still, even with this review, there remains significant room to submit unit bids without triggering a low-bid rejection. The screening procedures are relatively coarse in Texas. Low bids are examined more closely when unit bids lie outside the stated bounds of -50 percent to + 200 percent of the unit bid estimate.

Figure 3 shows the distribution for relative unit bids – the unit bid divided by the state's unit bid estimate. The chart contains over 1.8 million bids (winners and losers) on individual items from the 6,287 auctions. The first thing to note that there is considerable spread in the submitted item prices relative to TXDOT's estimate of the unit cost of the item. The interquartile range goes from .78 to 1.45 with the median at 1.04. The distribution has a long right-hand tail which has been truncated at 5. If one focused only on the winner's relative unit bids, the interquartile would narrow by 10 percent. This shows the distribution of relative bids is quite disperse at the item level, offering the possibility that firms could be submitting unbalanced bids.

In order to take advantage of such a possibility, ex-post quantities installed would have to differ from the ex-ante estimates. Evidence on this activity is presented in Figure 4. The figure shows the distribution of the relative difference between quantities installed and estimated quantities from winners' records. The data include all original items for the 6,287 completed auctions for the period 2004 through 2011 and includes roughly 383,000 individual bid items. The figure shows that 43 percent of the items have quantity installed equal to the estimated quantity, 21 percent of items have under runs, 25 percent experience over-runs and 11 percent of items are deleted from auctions. Deleted items are often replaced with new items. Because of the relatively large mass of deletions, the median change for the entire distribution of original items is negative at -6.11 percent. The overall differences in estimated versus actual quantities suggest there may be potential benefits in the submission of unbalanced bids. The question is whether bidders can actually exploit the environment and this depends on whether contractors have superior information to the state in assessing the actual quantities a project will require.

To examine this issue, we estimate the relationship between relative unit bids and

and omissions in design plans, to know about current site conditions, or perhaps to aggressively renegotiate contract terms in the construction phase.

under- and over -runs. The basic regression model is

$$\frac{b^i_{ka}}{b^{ece}_{ka}} = \lambda(\frac{\Delta q^o_{ka}}{q^{ece}_{ka}}) + \rho_k + \delta_t + \nu^i_{ka} \tag{3}$$

where the dependent variable is the relative unit bid of bidder i in auction a for item k. b^{ece}_{ka} 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 main independent variable (the first term on the right hand side) 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 key parameter in the equation is λ and it measures the relationship between deviations in actual quantities from estimated quantities and the relative unit bids submitted by contractors. If firms are submitting skewed bids to increase revenue, one would expect λ to be positive. The model also allows for the inclusion of item-level fixed (ρ_k) and year effects (δ_t). If bidders are increasing some bids in a auction while decreasing others in the same auction, one would expect the errors of the model to be correlated at the bidder-auction level. Therefore, all models will be estimated clustering the standard errors at the bidder-auction level.[15]

The results from the regression analysis are presented in Table 3. The first column reports the results from only including the quantity Δ variable and year effects. The coefficient on the quantity change is small and not statistically significant. The next column includes item fixed effects, but there is no change in the sign or significance of the coefficient on the quantity variable. The third column of the table includes an interaction term between a bidder experience dummy and the relative change in quantity variable, along with an indicator variable for experienced bidders. The idea is that perhaps only more experienced bidders have the expertise to assess the likelihood of under- and over-runs. More experienced bidders are defined as firms that have bid more than 10 times in prior

[15]The empirical model is similar to the one 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. 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.

auctions.[16] The interaction term is not statistically significant at the 5 percent level, indicating the ability to exploit unbalanced bidding does not differ across bidder types. More experienced bidders do, however, submit lower relative bids, on average. The fourth column adds an interaction term for the period 2004 to 2006 – the high change order period. The effect of under and over runs on relative bids is no different across the two periods and neither parameter is statistically significant. at the 5 percent level. The final column weights the regression by state's estimated total cost for the item. This gives larger weight to more important items in the project. The coefficient on the change in quantity is now positive and statistically significant at the 5 percent level but the magnitude of the effect remains very small.[17]

The item-level regressions suggest that bidders do not increase (decrease) unit bids on items that over (under) run. As a last piece of evidence, we perform an auction-level check and compare the revenue generated by the submitted bids to an alternative strategy where the bidder submits balanced bids. Under the balanced-bidding strategy, a bidder uses the distribution of TxDOTs unit-bid estimates as the basis for their bids, adjusting for the overall level of bid submissions. 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. We then compare the revenue earned under this alternative bidding strategy to the revenue earned under the submitted unit bids using the actual quantities installed. If a contractor can anticipate quantity changes, one would expect revenues to be higher under the bidder's submitted price list 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 submitted bid and the alternative 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

[16] To construct the experience variable, we use data from the entire time period 1998 through 2011.

[17] Specifications were also estimated that dropped deleted, included lump-sum items, and used the sieve approach described in Miller (2014). We discuss this latter exercise in the appendix. In short, the coefficients on the quantity change variable remained close to zero and not statistically significant in all these exercises.

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. Our conclusion is twofold. First, bidders do not appear to systematically increase payments through the submission of skewed or unbalanced bids in these auctions in Texas. Second, bidders do not appear to be able to anticipate well changes in quantities at the item level. In correspondence with TxDOT officials, they reported to us that a search of records for the last five years indicated that there were no cases of low bids being rejected because of unbalanced bids.

This muted relationship between relative unit bids and changes in item-level quantities was also seen in the California study by BHT.[18] However, in that analysis, a strong relationship between change orders and bidding was found at the auction level. Perhaps bidders can anticipate projects that are likely to require modification but cannot easily identify the impact of such changes on individual components. It is this analysis that we turn to next.

5 The Project-Level Bid Model

In this section we describe an empirical model that incorporates project 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

$$bid_i = \sum_{k=1}^{G} b_k^i q_k^o \tag{4}$$

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

$$Revenue_i = \sum_{k=1}^{G} b_k^i q_k^o + \sum_{k=1}^{G} b_k^i \Delta q_k^o + \sum_{m=G+1}^{T} b_m^i q_m^n \tag{5}$$

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

[18] Nystrom (2015) also finds no evidence of unbalanced bidding using Swedish construction project data.

earned on the new items. In setting up the model, we assume that bidder's can anticipate the ex-post modifications, the same approach as in BHT. It amounts to assuming that contractors can anticipate project 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 project modifications.

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

$$cost_i = \sum_{k=1}^{G} c_k^i q_k^o + \sum_{k=1}^{G} c_k^i \Delta q_k^o + \sum_{m=G+1}^{T} c_m^i q_m^n \tag{6}$$

The costs include both the costs of installing the original items, c_k^i, along with the costs associated with project 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. The particular new item prices may be negotiated but are often priced using recent prices paid on the item or by what is known as force accounts. 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.[19]

Bidders i expected profit from the project is then

$$\pi_i = \left[\sum_{k=1}^{G} b_k^i (q_k^o + \Delta q_k^o) + \sum_{m=G+1}^{T} b_m^i q_m^n - \sum_{k=1}^{G} c_k^i (q_k^o + \Delta q_k^o) - \sum_{m=G+1}^{T} c_m^i q_m^n \right] * (pr(s^i) < s^j) \tag{7}$$

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 maximize expected profits factoring in the magnitude and nature of expected project

[19] 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.

modifications. 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 a two stage problem – choosing the optimal b_k's and the optimal score s^i. Taking the derivative of (7) with respect to each of the original tasks G, summing across the G first order conditions, and solving for the bid yields

$$\begin{aligned}\sum_{k=1}^{G} b_k^i q_k^o = \quad & \frac{1}{G}\sum_{k=1}^{G}\frac{(q_k^o + \Delta q_k^o)}{q_k^o}\Bigg)\left(\sum_{j\neq i}\frac{h_j(s^i)}{(1 - H_j(s^i))}\right)^{-1} \\ & + \sum_{k=1}^{G} c_k^i q_k^o + \sum_{k=1}^{G}(c_k^i - b_k^i)\Delta q_k^o + \sum_{m=G+1}^{T}(c_m^i - b_m^i)q_j^n \qquad (8)\end{aligned}$$

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.[20] 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.

5.1 Empirical Model

The FOC obtained in equation (8) forms the basis for our estimating models. The key elements we need to model are costs, the markup term, and the role of project modifications. We model bidder costs to complete a project as a combination of auction characteristics and idiosyncratic bidder costs. The analysis estimates the markups using a standard structural auction model. Project 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 project modification, as opposed to observing the realization. To address this issue, we treat the problem as an errors-in-variable matter and

[20] 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 with the exception of the penalty term. 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.

use an instrumental variables approach. The various components are then incorporated into a structural model that estimates the effect of project modifications on bidder costs.

5.1.1 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 as a. We will assume that bidder i estimated costs for the original items in project a takes the following form:

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

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 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. These variables have been used in prior studies to control for project heterogeneity. For example, 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)). Our strategy here is to include a detailed set of cost control variables to reduce the likelihood that the parameters on the project modification term suffers from an omitted variables problem. η_{ia} reflects bidder specific idiosyncratic cost and is assumed to be *i.i.d.*.

5.1.2 Markup Estimation

The structural version of 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, Kosompoulou and Lamarche (2012) and Bajari, Houghton and Tadelis (2014). The first step estimates a relative bid model that controls for auction

[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.

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 that the probability that bidder i's bid is greater than bidder j's is

$$H_{ja}(b) = Pr(x'_{ja}\mu + \theta_a + \epsilon_{ja} \leq s^i_a) \equiv G_N(b_{ja}) \tag{11}$$

where $b_{ja} = s^i_a - x^{'}_{aj}\mu + \theta_a$ and 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 (14) 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 of 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 weight distribution 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.

5.1.3 Project Modifications

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

$$\sum_{k=1}^{G_a}(c_k^i - b_k^i)\Delta q_k^o + \sum_{m=G_a+1}^{T_a}(c_m^i - b_m^i)q_m^n = (\tau - 1)netflow_a = \gamma netflow_a \qquad (13)$$

The project 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 project modifications. If τ equals one, then the impact of project modifications of contractor profits would be zero, as contractors would be just compensated for the costs incurred. If τ is less than one, contractors revenues exceed costs when project modifications occur. This could be the case, for example, if contractors can generally exercise monopoly power during the construction phase when negotiating prices for the new items. If τ is greater than one, then costs exceed payments. This is the adaptation cost finding of BHT where bidders adjust up their bids for projects where the likelihood of project modifications is high. 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 strong negative correlation in the data. This is because substitution is common between original and new items in this setting. We do explore alternative forms of the project modification variables below and we estimate models substituting the variable $grossflow_a$ for $netflow_a$.

As mentioned earlier, a key issue is the fact that the project modification variable is an ex-post realization. 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 project modifications. The expected value of project 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.[22] The solution is to identify instruments

[22]Miller(2014) takes a similar approach in estimating a model where bidders form expectations about

correlated with the signal of the expectation of the project 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 engineer is the TxDOT employee that manages the construction project and initiates change orders. For each area engineer, a lagged change order activity measure was constructed using the prior two years of contracts that the area engineer oversaw. The specific variable is the average number change orders per project an area engineer submits for projects let 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 activity. We utilize a time varying instrument to allow for the fact that change order policy shifted over our period of analysis. The moving average of past change order activity declines steadily over time from a mean of 21.4 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. This instrument ended up being only weakly correlated with the $netflow_a$ and $grossflow_a$ variables. We also allowed interactions between the past experience of a bidder with an area engineer and the other instruments. None of these additional instruments or interactions improved the performance of the instrument variable estimation. The appendix discusses using area engineer fixed effects as a possible set of instruments.

5.1.4 Model Estimation

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

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

The structural estimating equation replaces the markup with an estimated markup and transforms the model into a specification that models the pseudo cost of a bidder, the left-hand side of (14), as a function of the project modification variable along with controls for project characteristics. The model of pseudo costs and project modifications will be estimated using instrumental variables, instrumenting the project modification variables

item-level changes in quantities.

with information on past change-order activity for the area engineering overseeing the project.

5.1.5 Descriptive Bid Regression

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

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

where z_a represents auction characteristics, x_{ia} represents bidder characteristics and r_{ia} are rival characteristics. 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. x_{ia} includes distance to the project, 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. The expected number of bidders is constructed using the history of past participation rates for all plan holders in the auction.[23]

6 Empirical Results

The results of the analysis are presented in Tables 5 through 10. Table 5 and 6 present the results from the descriptive regression analysis; Table 7 shows the distribution of markups generated from the structural auction model; and Tables 8 and 9 present the results from the empirical analysis of bidder costs. Throughout the empirical analysis, we estimate models pooled over time and broken out into two time periods: 2004-2006 and 2007-2011. The first period is one of relatively high change orders and the second period low change order activity. The bid, pseudo costs, and project modification variables are normalized by the ECE. The descriptive regression models are estimated with indicator variables for project type dummies, geographic zone, month and year. In the structural model, we

[23]See Hendricks, Pinske, and Porter(2003). The appendix provides additional details on measurement of own and rival bidder characteristics.

present specifications with and without the additional project-level controls. For each model, specifications that include the $netflow_a$ variable and specifications that include the $grossflow_a$ variable are estimated. All models include standard errors that are clustered at the auction level.

6.1 Relative Bid Regression

Table 5 presents the results from the ordinary least squares model for equation (15) where the measure of contract incompleteness is the $netflow_a$ variable. The first column of the table reports results without the project-level characteristic variables – number of tasks and length of project – included in the model. The coefficient on $netflow_a$ is positive and statistically significant at the 5 percent level. The size of the coefficient indicates a very modest effect – at the mean level of $netflow_a$ – bidders would shade up their bids by .005 or less than one percent. The other variables in the model have the expected signs. An increase in the expected number of bidders decreases bids. Bids increase with increases in bidder distance to a project and with capacity utilization. Fringe firms submit higher bids, on average, as well. If rival's are closer or if rival's have low capacity utilization, this also increases bids. In short, the standard variables have the expected signs. The next column adds in project-level cost control variables. The coefficient on $netflow_a$ is unaffected. Bids rise with the number of tasks and decline with calendar days. The number of tasks variable has been interpreted as reflecting project complexity. An increase in the number of tasks is likely associated with higher costs. The calendar day result could reflect more flexibility in the work schedule, holding project size fixed. The next columns split the sample between the two periods. The coefficients on the project modifications variable is larger in high change order period compared to the low change order period – though the difference is not statistically significant at the 5 percent level.

Table 6 replaces the $netflow_a$ with the gross flow version of the variable. While the coefficient is smaller, the implied magnitude of the effect at the mean of the $grossflow_a$ variable is actually larger. Evaluated at the mean, relative bids are about .01 higher across the specifications. This is true both pre- and post the shift in change order policy. This gross change order variable may be a better measure of the disruptions associated with change orders, as the net flow variable can mask the overall level of modification activity. The coefficients on the remaining variables are quite similar. Overall, the OLS results suggest a modest positive correlation between project modifications and relative bids, with little difference across the two sample periods. In the Appendix, we also show results from a set of alternative specifications. The OLS models were also estimated utilizing project random effects specification, imposing some additional sample restrictions associated with project completions, and providing a disaggregation of our project modifications variables by type of change order. In short, we found the OLS results are robust to the random effects specification and to restrictions on the sample. Disaggregation by type of change order, yields similar results in terms of magnitudes of coefficients with project modifications associated with specific design and site having somewhat larger effects and over- and under-runs a smaller effect. However, on balance, the OLS results changed little across the various alternative specifications.

6.2 Structural Results

The above analysis shows a modest correlation between project modifications and the bids submitted in Texas highway procurement auctions. The models are descriptive in nature and in this section we look at the structural results. The structural approach provides an estimate of the effect of project modification variables on bidder costs. Before proceeding to the main results, Table 7 presents information on the distribution of the markups generated in the first part of the structural 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.[24] 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 5 depicts how markups vary by the number of bidders in our auctions. As the number of bidders increase, estimated median markups decline.

The main results from the structural model are presented in Table 8. The top panel shows the results from the models that uses $netflow_a$ as the measure of project modification. The bottom panel presents the results from the $grossflow_a$ models. For each project modification variable, results are presented for the three sample periods and for three spec-

[24] BHT report a median markup of .038 for paving contracts in California for 1999 to 2005.

ifications. The three specifications differ by the project controls variables included in the specification: (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 project complexity and project number of days variables. We alter the project variables to assess how sensitive the overall results are to controls for project heterogeneity, that is, to the functional form specified in equation (9). All models normalize the estimate of bidder costs by the state's engineers cost estimate.

At the bottom of the panels, the F-statistics from the first stage of the IV model are presented. The F-statistics are lower for the $netflow_a$ variable but still exceed the critical values in the standard Yogo-Stock test statistic for the overall sample and for the 2004-2006 sample. The F-statistics are smaller in the $netflow_a$ models that use the 2007-2011 sample, indicating that the instrument is somewhat weaker in the second period. The F-statistics are generally much larger in the models that utilize the $grossflow_a$ variable as the measure of project modification. This is true in all three of the estimation samples. Our overall sense is that the past change order activity of an area engineer acts as an adequate instrument for our measures of project modifications in these models.[25]

Next, we focus on our main results from structural empirical model. There are several central findings. The first is that the project modification effects are much larger than the estimates reported in the least squares models for pooled model and for the 2004-2006 subsample. The second main 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 project modification activity on bidder costs. In the specification that includes the full set of additional project controls, the project modification variables are often not statistically significant at the 5 percent level in either of the two sub-sample periods.[26] The inclusion of the complexity variable is the most important dampener of the project modifications effects. Third, none of the coefficients on the project modifications variables in the low change-order period (2007-2011) are statistically significant at the five percent level. Fourth, our proxy for the project complexity variable (number of item in an auction) raises bidder costs and the empirical magnitudes are very similar in magnitudes reported

[25]The coefficients on the past change orders by an area engineer variable are positive in all the first stage models.

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

in the OLS results in Tables 5 and 6. The log of calendar days lowers relative costs. Again, we think this might be associated with greater scheduling flexibility for projects that have more contract days, holding project size fixed.

In order to assess the effect of project modifications on bidder costs, we calculate the effect of project modifications on bidder relative costs evaluated at the means of our project modification variables for the three sample periods. The results of this exercise are presented in Table 9. In the 2004-2006 period, bidder costs are estimated to be 4 to 6 percent higher evaluated at the mean of our project modification variables compared to projects that experienced no project modifications. This is taking an average across the three specifications. In the 2007-2011 period, the average effect falls to 0.5 percent and 1.5 percent for the $netflow_a$ and $grossflow_a$ models, respectively. The overall results here broadly support the findings in BHT based on the California data, though the empirical magnitudes are smaller. BHT does not include additional cost controls in their empirical structural model, so their results are closest to our "no controls" specifications. Even without additional cost variables, our approach, along with BHT's, does control for the engineering cost estimate – a very good proxy of project-level cost heterogeneity. An alternative view, however, might be to give more weight to those models that include the full set of additional cost controls. In this case then, there would be no statistical difference between the estimates on the project modification variables in the 2004-2006 period and the 2007-2011 period. What we would say is that it appears that project modifications modestly increase costs but the results are not robust to splitting the sample. At a minimum, we find no evidence that bidders bid less aggressively in response to the reduction in the use of change orders. This could have been the case if modifications were viewed as opportunities to raise profits in the construction phase or if bidders were not being fully compensated for modifications that occurred.

6.2.1 Robustness Checks

In addition to the alternative specifications already presented in Table 8, we also performed an additional set of robustness exercises on the structural results. 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. To assess, whether our results are affected by such right censoring of projects in the data, we omitted the last two years from the analysis.

Our reasoning for keeping projects in the sample in 2010 and 2011 is that we wanted a longer time period and more post-recession years to assess the effect of the shift in the change-order policy on bidding. Tables A.6 in the appendix shows that the coefficients in the pooled sample (2004-2009) and the second period sample (2007-2009) are quite similar to those reported in Table 8.

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.7 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 generally robust to differences in the truncation point chosen. When we allow for negative pseudo-costs, the results are somewhat more muted. We rejected the alternative to dropping such observations as these high margin producers represented disproportionately winners in the auctions.

Finally, we also explored altering the definition of the project modification variables. The OLS robustness results reported in Table A.5 show that there are some differences across the type of project modifications. In particular, bidding is less correlated with the over- and under-run terms as compared to project modifications associated with new items. We reran all the models in Table 8 redefining the project modification variable only using the contributions from new items. The results are quantitatively and qualitatively similar for the both overall sample and the split samples.

7 Conclusion

The overall interpretation of our main results is that project modifications increase bidder costs and that the increase in bidder costs is above and beyond the direct costs associated with the change orders. To be sure, we know from documentation on change order procedures that bidders are compensated for the actual costs of the change order itself. However, the estimated increase in bidder costs shown here is in the same spirit as the adaptation cost interpretation in BHT. In their view, adaption costs are adjustment costs that contractors have to incur to incorporate modifications into the existing project. This could involve the resequencing of tasks, costs associated with renegotiation contracts, or extra technical staffing to deal with the uncertainties that project modifications introduce into a project. Our results suggest that contractors do incorporate the likelihood of disruptions or adaptation costs associated with project modifications into their estimates of project costs at the bid-letting stage and this leads to higher procurement costs for the state. At the same time, we found no evidence that bidders could exploit unbalanced bidding strategies to increase payments in the construction phase.

TxDOT's change project modification policies resulted in a decline in the direct costs associated with change orders and most likely a reduction in the adaptation-type costs associated with such modifications. Still, we recognize that the statistical significance of the results are sensitive across specification. A more conservative way to interpret our results would be that there is no evidence that bidders responded to the reduction in project modifications by bidding less aggressively and undoing the cost savings associated the reduction in change-order budgets.

A final point is that the TxDOT experience illustrates that project 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 project modifications through an explicit change in budgeting and project management rules. One possibility is that this shift in change order policies might have induced as increase in project engineering and/or construction management efforts. To check on this, we obtained information on TxDOT's cost for pre-engineering and construction management over the period 2004-2011 for the projects in our sample. 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 10). This suggest that TxDOT accomplished the reduction in project modifications without increasing their internal project costs.

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8 Appendix

The Appendix describes in greater detail the creation of the dataset, measurement issues surrounding change orders and project modifications, detailed definitions of the full set of variables used in the paper, and a set of robustness exercises.

8.1 Data

The data come from TxDOT's computer archives of their bid lettings and project management systems. The bid-letting data captures information provided to contractors at the bid-submission stage and records the outcomes of an auction. The project management system captures information on payments made on the contract in the construction phase, along with details regarding change orders to the project.

8.1.1 Project-Level Data

The bid-letting information includes all highway construction contracts let from September, 1997 through December, 2013. The organization of the information is at two levels – the project level and the item level. The project- or auction-level data from the bid letting contain an overall description of the project, the date of the bid letting, the location of the project, the state's estimate of the cost of the project (ECE), the estimated length of the project in calendar days, the start date of the project, the name of the TxDOT engineer managing the project, a name and address list of contractors purchasing plans (planholders), a list of the submitted bids by planholders, and the identity of the winner of the auction, if any. The ECE is a critical variable in the analysis. This is TxDOT's estimate of the cost of the project. The ECE is included in the bid-letting documents and available to all potential bidders prior to the bid letting. The ECE is highly correlated to submitted bids. A regression of the bid on the ECE yields an adjusted R^2 of .969, indicating that the ECE is a very good proxy for cross-project cost heterogeneity.

Project heterogeneity is also summarized by several other variables in the data. We classify projects into three distinct types of projects – paving projects, bridge projects and all other projects. Each project group makes up roughly one-third of the overall sample (Table 1). In addition, previous studies have used both the number of distinct items that are part of a project and the estimated length of the project in terms of number of contract days to control for cost differences in projects. The number of tasks in a project is often interpreted as proxy for project complexity. The number of items across project varies substantially in our data. At the 10th percentile of the project-task distribution, there are 15 items per project. At the 90th percentile, there are 125 items per project. Calendar days shows similar 10-90 variation, going from 37 to 340 contract days. This information on number of items and calendar days is provided to bidders at the bid letting stage. In the models, the variables are included in logs. Projects are also identified by location (in one of 5 of the state's construction zones) and by the date of the bid letting.

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 over 98 percent of non-maintenance, completed projects. Still, the 2004-2011 sample does face selection, as a number of the largest projects let late in the sample are not complete by the end of of 2013. 93 percent of 2010 projects let and 83 percent of 2011 projects let are completed by the end of 2013; however, the very largest projects are not completed. The average size of the 2010 completed projects is 69 percent of 2010 projects let and the average size of 2011 completed projects is 35 percent of average size of 2011 project let. This difference in completion rates by number versus size reflects the skewed nature of project size. To assess the impact of selection on change order activity, we examine how $netflow_a$ and $grossflow_a$ varies with project size and project length. Project completion is linked closely to project size and length (in days). We use the normalized $netflow$ and $grossflow$ reported in table 2 and correlate these at the project level with project size, measured as the ECE, and project length, measured by number of calendar days, for our overall sample (2004-2011) and an the earlier sample (2004-2009). The correlation coefficients between the project modification variables and project size and length are all less than .050 (in absolute value) for both the 2004-2011 and 2004-2009 samples. We also check to see whether the results of the empirical models are sensitive to restricting the second period samples to 2009 and that is not the case. We discuss these results below in a set of robustness exercises.

8.1.2 Bidder Information

The project-level data allow us to construct variables that describe a set of characteristics for planholders. In order to bid on a project, a contractor must be a planholder – i.e., purchase a plan. The planholder list for a project is public information available prior to bid letting, so that all potential bidders know the set of potential rivals. The actual costs to obtain a plan are relatively minor but TxDOT will only sell plans for a project to pre-qualified bidders. Bidders are pre-qualified by TxDOT based on the financial resources of the bidder (audited financial statements) and prior experience on TxDOT construction projects. Each contractor has a unique vendor identification number which allows us to track an individual contractor over time. There are a small number cases where vendor id's change over time for a contractor. These are corrected in the data.

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.

For each contractor in the data, a measure of capacity utilization is also constructed. The measure of capacity utilization is the current backlog divided by the maximum backlog observed in the data. 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 planholders in the data set. At the start of the panel in 1997, 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 in a straight-line fashion. If a project is estimated to take 6 months, then 1/6 of the value of the project is assumed to be completed during the month. The length of the project is constructed using the calendar day variable. The substantial number of years of data available prior to the analysis sample (1998-2003) allows us to initialize the backlog series with over five years of data.

The rival variables are constructed by taking the minimum distance and the minimum capacity utilization from the other planholders in an auction. The expected number of bidders is based on past bidding participation patterns for each planholder in the auction. For each planholder, 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 planholders of the past participation variable. Bidder participation is updated after each bid letting. For new firms that appear in the sample, the average participation rate of new firms is used. One can estimate the model using the actual number of bidders and the results are similar, though the coefficient on the number of bidders is somewhat larger in absolute value than the coefficient on the expected number of bidders reported on Tables 5 and 6 in the paper.

8.1.3 Item-Level Data

The item-level information at the bid-letting is a list of all items that define the tasks to be completed in a project. Across the auctions in our sample the average number of items per project is 61 items (Table 1). Each item is a specific task to be completed. An individual item could be the amount and type of asphalt to be used on a paving project, the length of the guardrail to be installed, the number and type of signage to be placed at a project, the square yards of earth that need to be moved, or the type, size and quantity of trees to be planted. Each item is described by an 8-digit code, a detailed description of the item, a unit of measure for an item (e.g., square meters, linear feet, gallons) and the quantity to be installed. The quantity to be installed is only an estimate and the actual quantity installed can and often does deviate from the estimate in the construction phase. TxDOT also provides the state's estimate of the unit cost of an item to be installed. This is referred to as the unit-bid estimate and is public information provided to bidders with the bid-letting documents. In constructing the over and under-run components of the project modification variables, the unit-bid estimate is used as the price in these calculations. There are also lump sum items which are an overall dollar value and are usually associated with mobilization costs. Mobilization costs are overhead costs paid to the winning contractor by a set formula based on the project start date and project completion thresholds.

For each item listed in a project, a bidder submits a price or unit bid. This is the payment the contractor will receive for the installation of a unit of the specific item. The overall bid of the contractor is then the sum across all items of the unit bid $\times$ the estimated quantity. TxDOT records the complete list of all unit bids for each bidder in an auction. In our data, the item-level detail on bids and the engineering costs always sum to the project level bid and ECE, respectively. In short, the item- and project-level data from the bid letting are internally consistent. The item-level data from the bid-letting are available to us from 1997 to 2013, encompassing over 4.5 million item-level bids.

8.1.4 Payments and Change Order Data

The last data source contains information on payments made on a project. The payments data are reported at both the project and item level. At the project level, information on the final payment (the project total) and the completion data is provided. We have this project-level data on payments going back to 2000. The item-level payments information contains the final quantity of an item installed, along with the price paid for the item. The price paid is the unit bid submitted by the winner for each of the original items. The payments data lists all the new items introduced in the project with both the quantity installed and the unit price paid. For the terms in the project modification variables, the winner's price was used in the calculation of the $netflow_a$ and $grossflow_a$ variables. Table A.1 provides a set of statistics on items for both original and new items and by the direction of change of the over and under-runs.

The payments data also provides a notation of whether an item was involved in a change order. 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. As mentioned above, there are many instances of item-level over- and under-runs that are not linked to an explicit change order. Because of this we treated all observed changes in original item quantities in the over and under-run terms. 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. The major categories include extra work or changes in 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 majority of overall negative adjustments occur in original item under-runs. In the $netflow_a$ measure of project modification, the positive and negatives are netted out; whereas in the $grossflow_a$ measure we take the absolute value of each item associated with the change order. Table A.2 provides a breakout of new items by types of change orders and across the three main estimation samples. 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 project modifications due to design and site issues fell from 0.050 to 0.031.

As mentioned above, each auction has at least one lump sum item associated with mobilization costs. In most cases, the winner is paid exactly what the submitted mobilization costs are so there is less uncertainty about lump sum payments. However, we do observe some cases where such lump-sum payments deviate from the bid amount. Because there is less uncertainty associated with lump-sum times, we re-estimated all the columns of Table 3 omitting the lump sum items and the results are the same as those reported in the paper.

8.2 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. The area engineer is an employee of TxDOT and each project is assigned an area engineer. The area engineer assigned a project is identified in the bid-letting documents and potential bidders are provided contact information for the area engineer if they have as questions about the plans before the bid-letting. The area engineer also manages the project in the construction phase and, importantly, initiates the change order process. 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. Area engineers cover specific geographic areas (or Districts). There are 5 construction zones in Texas divided into 25 smaller Districts. In our sample, we observe 158 different area engineers working across our 5 construction zones.

For each area engineer, we construct a variable that measures the average number of change orders submitted for projects let over the prior two-year period. For each project, we know the number of distinct change orders issued by the overseeing area engineer. As in BHT, we assume that certain engineers are more or less likely to utilize change orders and that bidders can use this information to assess the likelihood of modifications on a specific project. Data on the number of change orders per project over time is available from 2001 onward, though we only have all the item detail for the years after 2003. We use a time varying measure – a moving average of the number of change orders issued – because we know that change-order policy shifted over time. The moving average of past change order activity declines steadily over time from a mean of 21.4 in 2004 to 12.3 in 2011. A model of the log of moving average of the number of change orders on area engineer fixed effects has an adjusted R^2 of .83 for our sample of 6287 projects, indicating persistence in change order activity by area engineer across the sample. For new area engineers that appear in our data, we use the average value in the period to initial the series.

We did explore 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 data. Table A.3 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.

8.3 Sieve Estimation

Miller (2014) suggests that an examination of skewed bidding should incorporate the fact that there are likely linkages across items within a project. This means that bidding on item 1 in a unit bid auction can be affected by the likely over and under-runs of other items in the auction. What this means is that each unit bid is a function of the expected quantity changes across all items in the auction. Because the number of distinct items can be quite large, simply including estimates of each item quantity change on the right-hand side of the regression model in equation (3) is not possible. Miller (2014) develops a method to deal with this issue employing techniques from sieve estimation. The idea is propose a set parameter restrictions on the right-hand side variables that allow one to group the individual items into a smaller set of groups. As a check of our results, we re-estimated the regression model in equation (3) using Miller's approach. This involves adding additional control variables to measure the changes in quantities both within groups of tasks and across groups of tasks. In our example, we identify four different main item groups: paving, bridge, earth, and miscellaneous work.[27] The results of this exercise are presented in Table A.4 and can be compared to the results in Table 3 in the paper. Looking across the set specifications estimated, we again find no evidence of skewed bidding.

[27]This resulted in 14 additional control variables being added to the regression model.

8.4 Model Robustness

We performed a set of robustness tests on the least squares and the structural IV models. In OLS models, we estimated a random effects specification controlling for project-level heterogeneity; a model estimated using only 2007-2009 data; and a model that incorporated different types of change orders as alternative controls for project modifications. Table A.5 shows the results from these exercises. The first two columns present the results from the random effects specification. The results are very similar to those reported in Table 5 and Table 6 for the 2004-2011 sample. The coefficients on the project modification variables are almost the same in the random effects models as in the OLS specifications. Columns (3) and (4) of the table restrict the second period sample to 2007-2009. This sample will be less affected by selection due to project completion requirement (discussed above). The parameters on the project modifications variables are very similar to those reported in column (4) in Tables 5 and 6, so that the basic correlations in the data are robust to this change in sample. The last two columns break out the project modification variables into categories based on the type of modifications. We include four breakouts: extra work, site and design changes, miscellaneous work, and over- and under-runs on original items. 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 5. In column 6, greater differences in parameters emerge but it is important to note that most of the gross flow 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 quite small, with the exception of the over- and under-run term. Still the results suggest that adjustments to bids may be more linked to new items, as opposed to over- and under-runs.[28]

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 9 in the paper. Table A.6 reports the results. Overall, our results are quite robust to the dropping of the two years of data. The coefficients estimates on the project modification variables from the pooled sample are similar in magnitude and statistical significance to

[28]The structural model cannot be estimated with this finer disaggregation because of limitations in the number of instruments available to us. BHT use the full set of area engineer dummies in their analysis; however, the area engineer information were relatively weak instruments when included as a full set of fixed effects. As mentioned above, this may be due to the fact that the use of change orders is shifting during our sample period.

those reported in the paper, and none of the coefficients on the project 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.7. 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 partials 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 8.

Table 1: Bidder and auction level summary statistics

Variables	Mean / count	(Standard deviation)
Bidder characteristics		
Number of completed projects	6,287	
Number of bids	30,061	
Relative bid	1.075	(0.245)
Relative winning bid	0.961	(0.187)
Distance to the project location (in miles)	205.057	(295.111)
Capacity utilized	0.281	(0.266)
Fringe bidder	0.773	(0.419)
Auction characteristics		
Number of paving projects	2,531	
Number of bridge projects	1,642	
Number of other projects	2,114	
Engineer's cost estimate (in millions of $)	3.905	(10.802)
Number of potential bidders	8.090	(3.917)
Number of bidders	4.781	(2.485)
Expected number of bidders	4.399	(2.098)
Number of days to complete the project	151.296	(154.228)
Number of items per project	60.982	(56.053)

Table 2: Net and gross change order flows by year

Year	Number of auctions	Mean	
		Net change order flows	Gross change order flows
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 3: Relative item bids

Variables	Relative item bids				
	Full sample				
	(1)	(2)	(3)	(4)	(5)
$\Delta q^o_{jk}/q^o_{jk}$	0.00018	0.00019	0.11790	0.03290	0.00179**
	(0.00011)	(0.00013)	(0.09500)	(0.02324)	(0.00076)
Experience bidder			-0.19829***		
			(0.06715)		
$\Delta q^o_{jk}/q^o_{jk} \times$ Experience bidder			-0.11771		
			(0.09500)		
$\Delta q^o_{jk}/q^o_{jk} \times$ Years 2004-2006				-0.03288	
				(0.02322)	
Item effects	No	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes
Weighted regression	No	No	No	No	Yes
Observations	1,828,846	1,828,846	1,828,846	1,828,846	1,828,846
R^2	0.00004	0.07981	0.07983	0.08031	0.10812

Robust standard errors clusted by projects and bidder 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: Regression results for relative bids with net flows

Variables	Relative bid			
	Full sample		Before 2007	After 2007
	(1)	(2)	(3)	(4)
Net change order flows	0.135***	0.131***	0.155***	0.097***
	(0.022)	(0.022)	(0.028)	(0.033)
Log of distance to the project location	0.005***	0.008***	0.001	0.012***
	(0.001)	(0.001)	(0.002)	(0.002)
Log of closest rival's distance to theproject location	-0.007***	-0.006***	-0.008**	-0.006**
	(0.002)	(0.002)	(0.003)	(0.003)
Capacity utilized	0.026***	0.021***	0.037***	0.008
	(0.006)	(0.006)	(0.010)	(0.007)
Rivals minimum capacity utilized	0.036	0.024	0.049	-0.034
	(0.025)	(0.025)	(0.033)	(0.039)
Fringe bidder	0.014***	0.019***	0.011*	0.023***
	(0.004)	(0.003)	(0.006)	(0.004)
Expected number of bidders	-0.006***	-0.006***	-0.008***	-0.006***
	(0.001)	(0.001)	(0.003)	(0.002)
Log of Project complexity		0.040***	0.048***	0.034***
		(0.004)	(0.008)	(0.005)
Log of number of days to complete the project		-0.028***	-0.030***	-0.028***
		(0.004)	(0.007)	(0.005)
Zone effects	Yes	Yes	Yes	Yes
Project type effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
Month effects	Yes	Yes	Yes	Yes
Observations	30,061	30,061	10,580	19,481
R^2	0.120	0.129	0.106	0.109

Robust standard errors clusted by projects are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Regression results for relative bids with gross flows

Variables	Relative bid			
	Full sample		Before 2007	After 2007
	(1)	(2)	(3)	(4)
Gross change order flows	0.043***	0.048***	0.042***	0.051***
	(0.010)	(0.010)	(0.013)	(0.014)
Log of distance to the project	0.005***	0.009***	0.001	0.013***
location	(0.001)	(0.001)	(0.002)	(0.002)
Log of closest rival's distance	-0.007***	-0.006***	-0.009***	-0.005**
to theproject location	(0.002)	(0.002)	(0.003)	(0.003)
Capacity utilized	0.027***	0.022***	0.037***	0.009
	(0.006)	(0.006)	(0.010)	(0.007)
Rivals minimum capacity utilized	0.029	0.017	0.049	-0.047
	(0.025)	(0.025)	(0.033)	(0.039)
Fringe bidder	0.015***	0.020***	0.012**	0.024***
	(0.004)	(0.003)	(0.006)	(0.004)
Expected number of bidders	-0.007***	-0.006***	-0.008***	-0.006***
	(0.001)	(0.001)	(0.003)	(0.002)
Log of Project complexity		0.042***	0.048***	0.037***
		(0.005)	(0.008)	(0.005)
Log of number of days to		-0.031***	-0.032***	-0.030***
complete the project		(0.004)	(0.007)	(0.005)
Zone effects	Yes	Yes	Yes	Yes
Project type effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
Month effects	Yes	Yes	Yes	Yes
Observations	30,061	30,061	10,580	19,481
R^2	0.117	0.127	0.100	0.110

Robust standard errors clusted by projects are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7: Estimated mark-ups

Regression sample	Mark-up		
	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 8: Structural 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 order flows	0.770***	0.743**	0.554*	0.950***	0.728**	0.435	0.126	0.670	0.656
	(0.225)	(0.294)	(0.290)	(0.354)	(0.345)	(0.324)	(0.521)	(0.541)	(0.590)
Log of Project complexity			-0.023***			-0.021***			-0.025***
			(0.005)			(0.008)			(0.006)
Log of number of days to			0.034***			0.046***			0.025***
complete the project			(0.005)			(0.008)			(0.007)
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 ident.	46.160‡	23.510‡	21.370‡	18.190‡	13.180†	12.730†	11.010†	9.895	7.835
Gross change order flows	0.232***	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 Project complexity			-0.030***			-0.027***			-0.030***
			(0.005)			(0.007)			(0.006)
Log of number of days to			0.039***			0.047***			0.032***
complete the project			(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 ident.	108.800‡	100.100‡	85.420‡	37.490‡	35.070‡	28.370‡	59.800‡	71.280‡	61.720‡

Robust standard errors clusted by projects 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.

Table 9: Project modification effects

Regression sample	Mean effects			
	Project controls			Mean
	None	Partial	Full	
	(1)	(2)	(3)	(4)
Net change order flows				
2004 – 2011	0.023	0.022	0.016	0.020
2004 – 2006	0.061	0.047	0.028	0.045
2007 – 2011	0.001	0.007	0.007	0.005
Gross change order flows				
2004 – 2011	0.055	0.039	0.030	0.041
2004 – 2006	0.092	0.065	0.041	0.066
2007 – 2011	0.004	0.021	0.019	0.015

Mean effects of the project modifications are calculated using coefficients in table 9 and averages of the project modification values

Table 10: Pre-engineering and construction management costs

Variables	Sample		
	Full sample	Before 2007	After 2007
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.

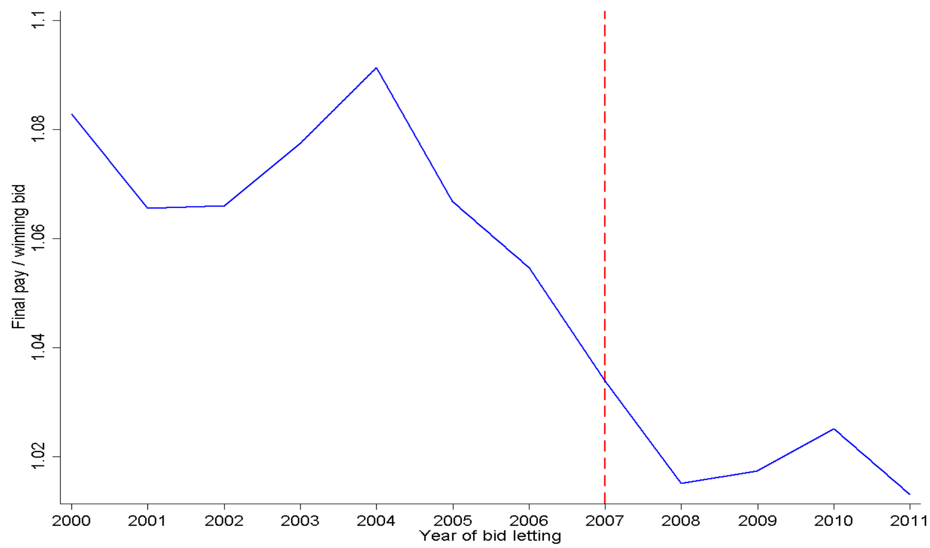

Figure 1: Final pay relative to winning bid

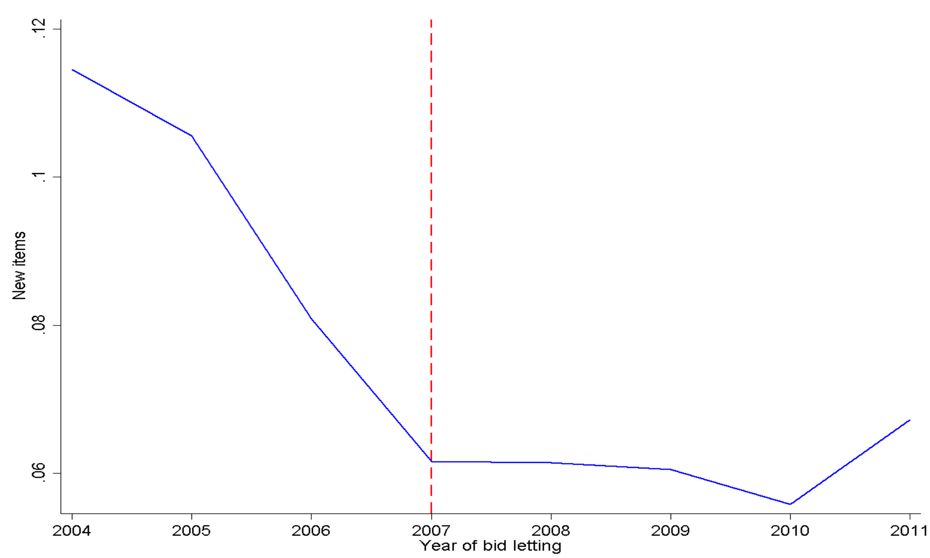

Figure 2: New items

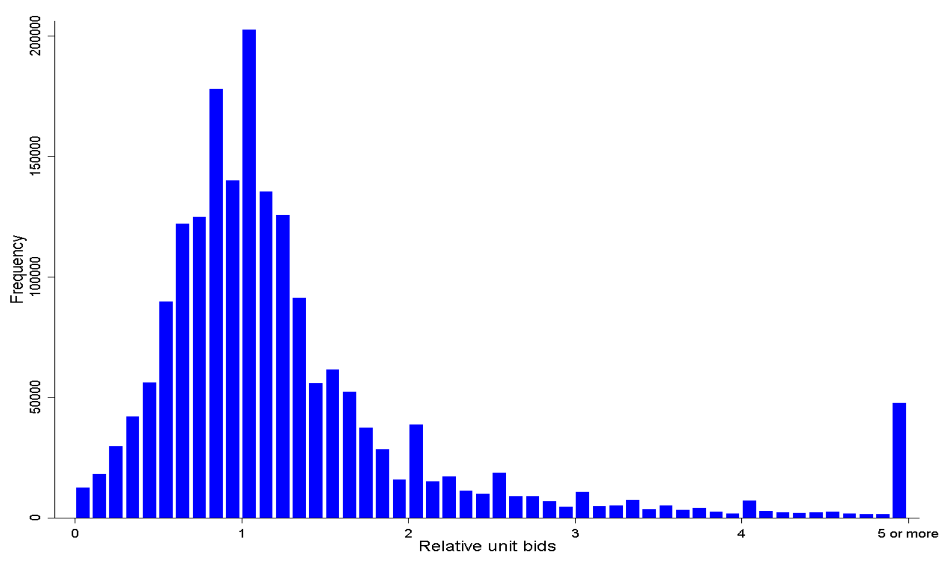

Figure 3: Distribution for relative unit bids

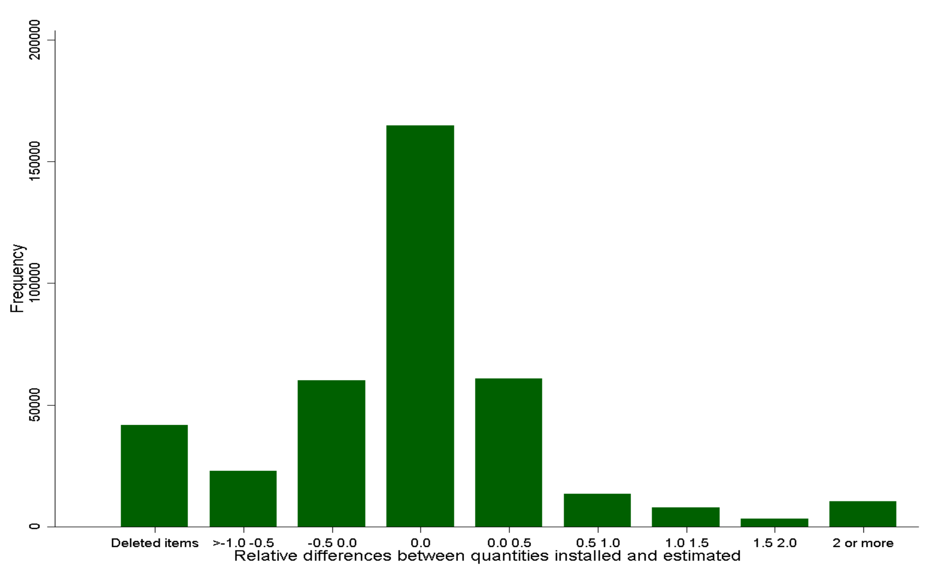

Figure 4: Distribution of the relative difference between quantities installed and estimated

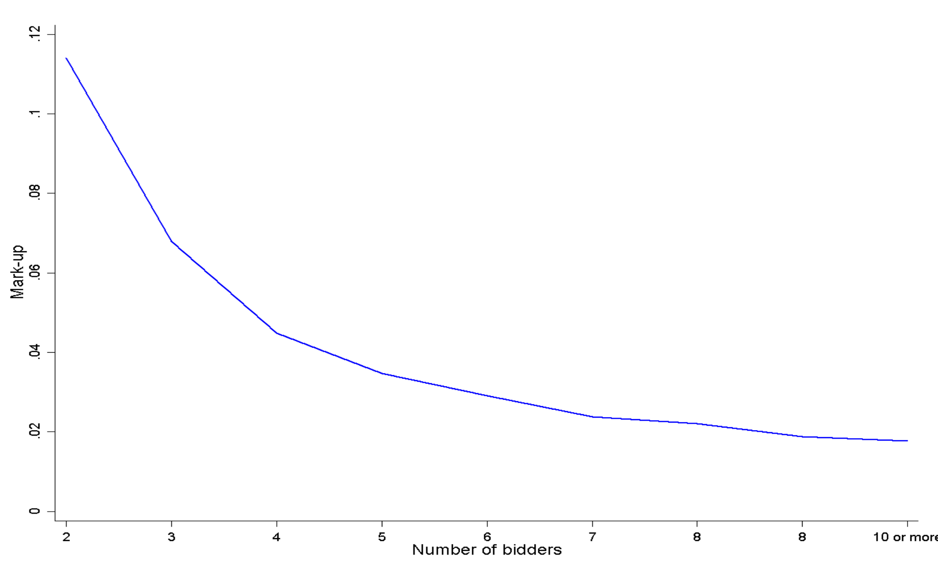

Figure 5: Median mark-ups by number of bidders

Table A.1: Item level summary statistics

Variables	Counts
Number of completed projects	6,287
Number of bids	30,061
Number of original items by all bidders	1,863,530
Number of original items by winner	382,933
Number of original unique items	24,783
Number of original price change items	5,598
Number of original items with over-runs	94,438
Number of original items with under-runs	82,412
Number of original items with no change	164,592
Number of deleted items	41,491
Number of lump sum items	7,342

Table A.2: Summary statistics by change order types

Variables	All years	Before 2007	After 2007
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.3: F statistics for weak identification

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

Table A.4: Relative item bids regression results with sieve parameters

Variables	Relative item bids		
	Full sample	Before 2007	After 2007
	(1)	(2)	(3)
$\Delta q^o_{jk}/q^o_{jk}$	0.00018	-0.00004	0.03270
	(0.00013)	(0.00003)	(0.02313)
Item effects	Yes	Yes	Yes
Year effects	Yes	Yes	Yes
Observations	1,828,846	705,951	1,122,895
R^2	0.08008	0.27744	0.00608

Robust standard errors clusted by projects and bidder are in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table A.5: Sensitivity analysis results for relative bids

Variables	Relative bid					
	All years		2007-2009		All years	
	(1)	(2)	(3)	(4)	(5)	(6)
Net change order flows	0.133***		0.111**			
	(0.020)		(0.045)			
Gross change order flows		0.050***		0.050***		
		(0.009)		(0.019)		
Extra work					0.097**	0.090**
					(0.038)	(0.039)
Net design and site work					0.166***	
					(0.032)	
Net miscellaneous work					0.223***	
					(0.057)	
Net over- and under-runs					0.081***	
					(0.022)	
Gross design and site work						0.134***
						(0.032)
Gross miscellaneous work						0.183***
						(0.056)
Gross over- and under-runs						-0.019
						(0.020)
Log of distance to the project	0.012***	0.012***	0.016***	0.016***	0.009***	0.009***
location	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)
Log of closest rival's distance	-0.006***	-0.006***	-0.009**	-0.009**	-0.006***	-0.007***
to theproject location	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
Capacity utilized	0.020***	0.020***	0.015	0.016*	0.020***	0.020***
	(0.004)	(0.004)	(0.009)	(0.009)	(0.006)	(0.006)
Rivals minimum capacity utilized	0.026	0.022	-0.022	-0.037	0.014	0.011
	(0.022)	(0.022)	(0.045)	(0.045)	(0.025)	(0.025)
Fringe bidder	0.010***	0.010***	0.036***	0.037***	0.020***	0.021***
	(0.002)	(0.002)	(0.005)	(0.005)	(0.003)	(0.003)
Expected number of bidders	-0.006***	-0.006***	-0.008***	-0.007***	-0.006***	-0.007***
	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)
Log of Project complexity	0.040***	0.040***	0.031***	0.033***	0.040***	0.041***
	(0.004)	(0.005)	(0.008)	(0.008)	(0.004)	(0.004)
Log of number of days to	-0.028***	-0.030***	-0.020***	-0.023***	-0.029***	-0.029***
complete the project	(0.004)	(0.004)	(0.007)	(0.007)	(0.004)	(0.004)
Zone effects	Yes	Yes	Yes	Yes	Yes	Yes
Project type effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Month effects	Yes	Yes	Yes	Yes	Yes	Yes
Random effects – Auction	Yes	Yes				
Observations	30,061	30,061	11,457	11,457	30,061	30,061
R^2	0.128	0.130	0.140	0.140	0.130	0.129
Wald χ^2	1,521.730	1,499.960				

Robust standard errors clusted by projects are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A6: Sensitivity analysis of the structural estimation results

Variables	Relative pseudo cost			
	2004-2009		2007-2009	
	(1)	(2)	(3)	(4)
Net change order flows	0.509*		0.521	
	(0.294)		(0.664)	
Gross change order flows		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	$19.130^{\ddagger}$	$54.700^{\ddagger}$	9.048	$27.190^{\ddagger}$

Robust standard errors clusted by projects 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.

Table A.7: Structural estimation results with varying truncation points

Variables	Relative pseudo cost					
	Full sample		Before 2007		After 2007	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: limits markup to 2×bid						
Net change order flows	0.426		0.234		0.668	
	(0.306)		(0.355)		(0.608)	
Gross change order flows		0.096		0.079		0.093
		(0.068)		(0.119)		(0.081)
Observations	29,877	29,877	10,452	10,452	19,425	19,425
F statistics for weak identification	$21.370^{\ddagger}$	$85.420^{\ddagger}$	$12.730^{\dagger}$	$28.370^{\ddagger}$	7.835	$61.720^{\ddagger}$
Panel B: limits markup to 0.5×bid						
Net change order flows	0.617**		0.542*		0.631	
	(0.289)		(0.322)		(0.581)	
Gross change order flows		0.139**		0.182*		0.088
		(0.062)		(0.104)		(0.078)
Observations	29,877	29,877	10,452	10,452	19,425	19,425
F statistics for weak identification	$21.370^{\ddagger}$	$85.420^{\ddagger}$	12.730	$28.370^{\ddagger}$	$7.835^{\dagger}$	$61.720^{\ddagger}$

Robust standard errors clusted by projects 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 complexity and calendar days in addition to project type, zone, month and year effects.