Strategic Bidding and Contract Renegotiation*

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Abstract

When firms bid in procurement auctions, they take into account the likelihood of future contract renegotiations. If they anticipate that certain input quantities will change ex post, they have an incentive to strategically skew their itemized bids, thereby increasing profits for themselves and costs for the procuring agency. We develop and estimate a structural model of strategic bidding using a dataset of road construction projects in Vermont. We find that firms engage in strategic bidding that increases profit margins by 3-4% at the project level, and 7-9% on the specific items that are renegotiated.

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1 Introduction

Most, if not all, procurement contracts are later renegotiated. These renegotiations are often precipitated by engineers determining, after the contract is awarded, that the actual requirements of the project differ from what was originally anticipated. In many contexts the rules for amending the contract ex post are carefully delineated. For example, the U.S. government's procurement regulations prohibit ex post price changes to a contract unless an item is added in the field or there is a relevant price adjustment clause (Kosmopoulou and Zhou (2014) and Kosmopoulou, Lamarche, and Zhou (2016)). However, adjustments to the quantities of labor and materials are not only permitted, but are commonplace.

Procuring agencies and contractors reasonably expect - are even certain - that renegotiations will ensue, but they are not certain of the precise nature of the changes. Moreover, it is widely acknowledged that firms modify their bidding strategies based upon their own expectations of subsequent alterations to the contract. These perceptions by industry participants are backed by past scholarly work. For example, in Athey and Levin (2001), forward-looking firms skew their bids in U.S. Forest Service timber auctions by submitting high (low) unit prices on types of timber in anticipation that the actual proportion of types of timber will increase (decrease) from original Forest Service estimates. Bajari, Houghton, and Tadelis (2014), in their study of the California highway construction industry, argue that contract renegotiations impose substantial "adaptation" costs on firms. They model firms' bidding behavior in anticipation of these costly renegotiations, and estimate adaptation costs of $2.20 for every dollar of additional work in the case of quantity increases. Our study examines how the prospect of ex post renegotiation in road construction projects in Vermont affects contractors' bids and profits. We find strong evidence that firms engage in strategic bid-skewing, and that it raises firms' profits.

Our paper differs from existing work in three important ways. First, while previous work (Bajari, Houghton, and Tadelis (2014) and Athey and Levin (2001)) assumes that bidders have perfect foresight and can anticipate renegotiation with accuracy, we assume that bidders form expectations based on the historical frequency of renegotiation. The frequency of renegotiation among items that have similar likelihood of been included in a contract specification often varies widely. Our model assumes that bidders internalize these probabilities at the time of bidding.[1] Second, we maintain that a thorough exploration of bid-manipulation in complex contracts requires careful examination of item-level bids, and that analysis of bid aggregates at the project level, while informative, does not reveal the extent to which firms strategically manipulate their bids. We employ itemized bid information to construct estimates of the markup of bids above costs, and we compare how they vary across auctions with and without positive quantity renegotiation. The variation in markups across items with different probabilities of renegotiation provides evidence on how firms' anticipation of change orders affects their bidding behavior. A possible concern is that change orders might be endogenous, due to unobserved heterogeneity in production costs. We confront this issue by employing a "quasi-experimental" empirical framework that permits direct comparison of items with and without renegotiation. Third, we conduct this work on a new data set of all construction projects undertaken by the Vermont Agency of Transportation over a five year period. One of the novel features of these data is that they include firm-level financial information, normally not available because of its proprietary character. Another is that it permits us to control for price adjustment clauses, which have been omitted in previous studies.

In the next section, we explain the renegotiation, or "change order" process for Vermont Agency of Transportation construction contracts. We also introduce our data, and conduct reduced form estimations that, on the one hand, illustrate the sensitivity of standard bid re-

[1] For instance, concrete has a frequency of negotiation of 30 percent in the period of analysis, while the task related to removal of structure has zero percent probability of being renegotiated.

gressions to different type of contract revisions, and on the other hand, suggest the existence and magnitude of bid-skewing. Next, we present a structural model of strategic bidding where firms expect adjustments to the quantities of work and materials in the contract, and we estimate costs and markups using this model. A study of the size of adjustments due to renegotiation at the project level can be used to assess the overall impact of uncertainty and firm heterogeneity on markups, but the test may confound such effects with influences from a number of sources, including adaptation costs. We circumvent this problem by focusing our analysis on a subsample of projects that have a similar set of tasks, and whose characteristics closely fit the Independent Private Value model. We use nonparametric estimation methods similar to the ones developed by Guerre, Perrigne, and Vuong (2000) and Bajari, Houghton, and Tadelis (2014) to estimate the distribution of latent costs after controlling for the remaining project heterogeneity.

We first perform the analysis at the project level, and in contrast to Bajari, Houghton, and Tadelis (2014), we find that increases in firms' costs on projects with renegotiations do not increase disproportionately relative to projects without renegotiations. This does not rule out the possibility of adaptation costs, but it does suggest that any adaptation costs that occur as a result of renegotiations at the item-level are not large enough to be detected when placed in the context of overall project costs. We find, however, that the magnitude of estimated markups is systematically higher for the project group experiencing positive quantity renegotiation; it varies across the quartiles of the distribution having a 3-4% difference at the median level. Considering itemized bids, both unit costs and markups are increased among items that were renegotiated after a project was awarded and the differences are more pronounced. Our results also show that while bidders increase their markups on items that have a high likelihood of renegotiation by 7-9% at the median level, they lower their bids and markups on items that are not renegotiated, to maximize their potential surplus ex post while maintaining the likelihood to win at a high level. The behavior leads to a significant increase in the cost of contracting to the state and the public, higher than that reported by studies considering all forms of renegotiation, rather than focusing like we do on quantity adjustments.

2 Data and summary statistics

2.1 An overview of change orders on Vermont transportation contracts

Our dataset consists of the complete bidding and payment records of all construction projects auctioned off between May 2004 and December 2009 by the Vermont Agency of Transportation (VTrans). There are 846 bids (more than 50,000 itemized bids) on 312 individual projects. We classify auctions by project type: asphalt projects, bridge projects and miscellaneous projects.[2] The agency awards contracts to the lowest bidders in sealed bid auctions held monthly. When advertising a project to the public, VTrans provides detailed engineer's plans and information on the work site, the required completion date and a brief description of the project.[3] The engineer's plans provide a list of quantities for each item in the project plan. All participants in the auctions are required to submit bids for each item on the list. The auction data include information on the identities of plan-holders, the identities of all bidders, their bids, the winning bid and engineering cost estimate for a project. Furthermore, we have a dataset on change orders, which includes the proposed quantity and unit-price for each renegotiated item within a contract and a brief description of the reasons for that change. Article 7.2.1 of AIA's (American Institute of Architects, 2007) document

[2]Miscellaneous projects include traffic signaling and lighting, grading and draining, parking lots and landscaping.

[3]Prequalification status is achieved by the successful completion of two procedures: (1) annual prequalification: the prequalification committee at VTrans annually assigns each firm certain limitations as to the value of projects and number contracts that they are allowed to undertake in Vermont; (2) contract prequalification: the process to obtain permission to submit a bid for a particular contract for a contractor who already obtained annual prequalification. See the Vermont Agency of Transportation Policies and Procedures on prequalification, bidding, and award of contracts for more details.

A201 defines a change order as follows:

> *"A Change Order is a written instrument prepared by the Architect and signed by the Owner, Contractor and Architect stating their agreement upon all of the following: .1 The change in the Work; .2 The amount of the adjustment, if any, in the Contract Sum; and .3 The extent of the adjustment, if any, in the Contract Time."*

Change orders are widely used in fixed-price contracts and are filled only if changes of plans or specifications are significant relative to the original contracts.[4] They include ex post payments made by positive quantity adjustments, price adjustments and new added item adjustments as well as payments made to VTrans due to negative quantity and dropped item adjustments. Hence, we have information on the actual quantity used in the field and the actual ex post payments in a contract.

Table 1: Descriptive statistics

Variable	Mean	Standard Deviation	Min	Max	Number of Observations
Winning Bid Amount	$1.806	$2.260	$0.025	$21.983	312
Engineering Cost Estimate of the Winning Contract	$1.910	$2.432	$0.026	$24.552	312
Change Orders Amount	$0.174	$0.323	-$0.117	$2.331	256
Bidding Amount	$1.730	$2.283	$0.025	$29.505	846
Relative Bid (before Change Orders: (Bid / Engineering Cost Estimate)	1.097	0.294	0.500	4.201	846
Relative Winning Bid (before Change Orders)	0.977	0.190	0.436	1.564	256
Relative Payment Amount (after Change Orders)	1.056	0.228	0.532	2.014	256
Price Adjustment Amount	$0.221	$0.240	$0.006	$1.047	41
Positive Quantity Adjustment	$0.154	$0.225	$0.000	$1.259	185
New Added Item Amount	$0.149	$0.312	$0.000	$2.689	222
Negative Quantity Adjustment Amount	-$0.119	$0.295	-$2.266	-$0.000	87
Dropped Item Amount	-$0.122	$0.250	-$1.591	-$0.000	130
Bidders (per Contract)	3.349	1.959	1.000	11.000	312
Plan-holder (per Contract)	5.026	3.163	1.000	16.000	312
Complexity (Number of Distinct Items per Contract)	60.228	35.346	2.000	245.000	312

All monetary figures are expressed in millions of dollars.

[4]For example, in the state of Vermont, a change order is recorded when it results in a cost increase of 5% or more on the item or causes an increase in the contract total pay amount.

Table 1 provides summary auction and change order statistics for the period of analysis. Winning bids on contracts are \$1,805,793 with an engineering cost estimate of \$1,910,227. Two hundred and fifty six contracts were supplemented by change orders making up 82.05% of construction projects auctioned off during our sample period. The average change order amount per contract is \$173,582. The relative bid, calculated as the bid divided by the engineer's cost estimate, is used as a measure of bidding aggressiveness. On average firms bid 9.70% above the engineering cost estimate and win with bids that are 2.30% below the engineering cost estimate. The relative final payment amount to winners resulting from the change order is 5.60% above the engineering cost estimate. In other words, winning bidders negotiate a 7.90% increase in payment relative to the winning bid. There is, on average, \$221,207 paid to contractors due to price adjustments, \$154,392 due to positive quantity adjustment and \$148,570 due to new added item amounts. In addition, \$119,065 and \$121,593 are the average payments firms make to the state when there are negative quantity adjustments and dropped item amounts, respectively. The type of renegotiation most frequently observed among projects during our sample period is related to new added items (86.72% of projects with renegotiations), followed by positive quantity adjustments (72.27% of projects with renegotiations). On average, the number of bidders and the number of prequalified plan-holders are 3.35 and 5.03 per auction, respectively. The number of different items per contract is used as a proxy for project complexity. The average number of items per contract is 60. The 846 contracts contain 50,465 items which are used in the reduced-form regression in the next section.

Figure 1 offers a nonparametric estimate of the probability density function of relative winning bids of initial contracts against the final relative payment amounts. It illustrates one of the striking features of contracting: change orders tend to increase payments for the state, and the increase tends to be more pronounced in the upper tail of the distribution. Different types of adjustments present vastly different challenges for the transportation agencies. Price

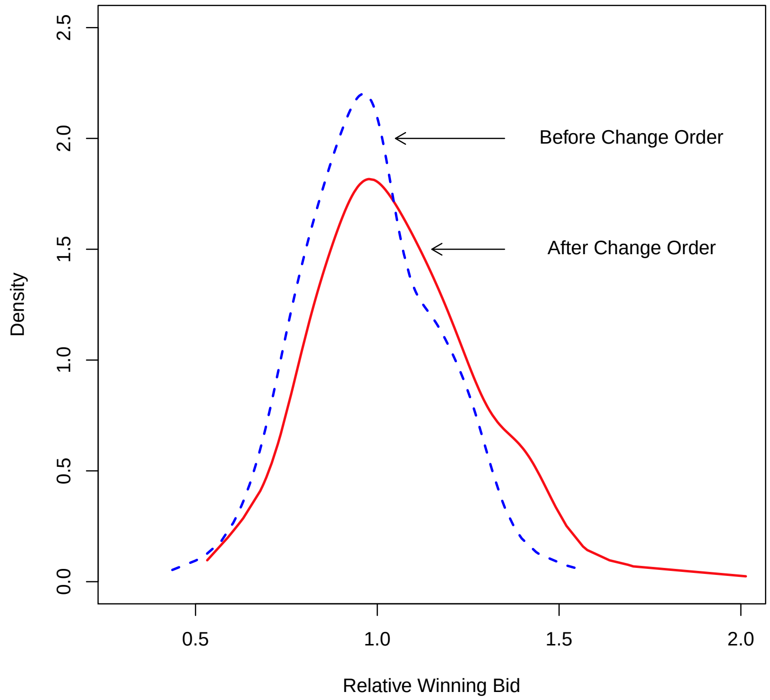

Figure 1: Kernel density plot of relative winning bids

adjustments are based on a market index that is independent of firms' reported bids.[5] They are triggered by fluctuations in the price of oil. Added and dropped items typically reflect unforeseen adjustments to a plan that are associated with project uncertainty. Since added items are not part of the original project plan, anticipation of them could only influence bids indirectly to reflect added uncertainty. Dropped items are a special case of negative quantity adjustments. Our focus is on quantity adjustments, as they provide clear incentives for bid skewing. Those adjustments are often due to errors in the engineers' plans that might be recognized by experienced contractors.

2.2 Reduced form estimation

This section presents a set of descriptive regressions to investigate the effect of renegotiation on bidding behavior. The basic model is as follows:

$$y_{iat} = \mathbf{X}'_{at}\boldsymbol{\beta} + \mathbf{W}'_{it}\boldsymbol{\gamma} + \mathbf{Z}'_{t}\boldsymbol{\delta} + m_t + \alpha_i + u_{iat}, \quad (1)$$

where the dependent variable, y_{iat}, is the logarithm of bid submitted by bidder i, in auction a, in month t. The independent variables comprise factors used to control for observed heterogeneity across bidders and projects. We include 1) auction specific characteristics ($\mathbf{X}$), 2) bidder and rival characteristics ($\mathbf{W}$), and 3) variables measuring general economic conditions ($\mathbf{Z}$). Table A.1 in the appendix provides a detailed definition on these independent variables. The model also includes monthly dummy variables, m_t's, and firm specific effects, α_i's. The error term u_{iat} is assumed to be the sum of an auction specific effect and a disturbance term i.e., $u_{iat} = \mu_a + \epsilon_{iat}$.

As mentioned earlier, there are five different avenues for additional payments to and

[5] The price adjustment amount depends upon the magnitude of deviation of the average fuel price from the index price during the project construction period and the quantities of the contract pay items subject to the price adjustment clauses. In this study, all projects have positive price adjustments, due to the continuous upward trend in oil prices over the period of our data.

from contractors: price adjustment, positive quantity adjustment, new added item amounts, negative quantity adjustment and dropped item amounts. Their amounts are used at the auction level as independent variables in our analysis. The vector **X** also includes measures of size and proxies of project uncertainty such as the log of the state's cost estimate of the project and the calendar days required to complete a project. The number of project components is used as a proxy for the complexity and the variable elevation captures related differences in the work site conditions. We control for differences in competition with the variable expected number of bidders, which incorporates the probability that a plan-holder will participate in the auction.[6] We also include indicator variables for project type to control for potentially different bidding behavior associated with asphalt and bridge projects.

We include a number of variables to control for bidder and rival characteristics. Consistent with prior literature, we construct each bidder's and rival's distance to work sites and their backlogs. We also include detailed financial information on each bidder such as assets, debt and revenue.[7] The information allows us to measure business strength and capacity more accurately, rather than resorting to local workloads as a proxy of firm activity based on state-level data.[8,9] We construct a financial leverage ratio, namely, the debt to asset ratio, in order to measure a firm's bidding reaction to financial constraints. Clayton and Ravid (2002) empirically test how the level of leverage affects optimal bidding behavior in a private value setting. Their empirical analysis of Federal Communications Commission (FCC) spectrum auctions found that firms with more debt are more likely to bid less

[6] In Vermont, plan-holders' identities are publicly available if the number of qualified plan-holders is larger than 3.

[7] Firms are required to provide financial information to VTrans in order to become qualified bidders. We obtained financial data about the firms from documents maintained by the Vermont Agency of Transportation.

[8] Vermont is a small state and almost half of the headquarters of contractors are located outside the state. Without knowing firms' business activity out of state we will not be able to assess the effect of their capacity constraints on bidding.

[9] The important of capacity constraints has been highlighted in the work of Jofre-Bonet and Pesendorfer (2003).

competitively. Kosmopoulou, Lamarche, and Zhou (2016) also show that smaller, typically financially constrained firms react positively to measures that reduce uncertainty.

In order to account for heterogeneity in size and experience across bidders, we designate a bidder as a top firm if its annual revenue is greater than 15% of the total value of all firms' revenues each year during the sample period.[10] To control for the possibility of systematic differences in the behavior of top firms and fringe firms facing financial constraints, we interact the debt to asset ratio with a variable indicating whether a bidder is a top firm. In addition, we also allow for differential bidding behavior in local markets by incorporating a measure of a bidder's local market power as an account of a firm's market share. A firm's local market power is defined by its working history at a county level. It is the proportion of all outstanding work in a county that is undertaken by a given firm. High values are associated with a firm having a dominant position in that county. Finally, it is also important to control for factors that reflect general economic conditions. We include two control variables, namely, a three month average of the number of building permits issued in the state and unemployment rate to capture the local business climate.

In columns 1-2 of Table 2, we estimate the project-level models using ordinary least squares (OLS) with clustered standard errors and then fixed effects to account for firms' different efficiency levels. The introduction of firm fixed effects controls for any additional idiosyncratic characteristic of individual bidders that may drive bidding strategies. All specifications include standard errors that are clustered at the auction level.

The coefficient on the ex post positive quantity adjustment amount is positive, but not statistically significant. The sign reverses when considering negative quantity adjustments, in line with expectations. Neither this nor the coefficients on new added and dropped items

[10] The highway construction market is highly concentrated in many states including Vermont. Based on 15% revenue threshold used in our analysis, we assign, on average, only 5% of the total firms in the market as top firms. The threshold allows us to assign a similar proportion of top firms to that in Bajari, Houghton, and Tadelis (2014).

Table 2: Regression results for a model of bids

	Project Bids		Itemized Bids	
Independent Variable	(1)	(2)	(3)	(4)
Positive Quantity Adjustment	0.095	0.120	0.011**	0.011**
	(0.075)	(0.083)	(0.005)	(0.005)
Negative Quantity Adjustment	-0.069	-0.132	-0.003***	-0.003***
	(0.097)	(0.097)	(0.000)	(0.000)
Price Adjustment	-0.211**	-0.276***	-0.162**	-0.203**
	(0.106)	(0.104)	(0.077)	(0.080)
Dropped Item Amount	-0.144	-0.198	-0.007**	-0.007**
	(0.124)	(0.125)	(0.004)	(0.004)
New Added Item Amount	-0.060	-0.110	0.057***	0.048***
	(0.116)	(0.114)	(0.018)	(0.017)
Log of Engineer's Estimate	0.913***	0.879***	0.900***	0.898***
	(0.017)	(0.018)	(0.005)	(0.005)
Log of Calendar Days	0.061**	0.083***	0.028*	0.036**
	(0.029)	(0.026)	(0.016)	(0.016)
Complexity	0.051	0.051	-0.004	-0.005
	(0.070)	(0.065)	(0.030)	(0.033)
Expected Number of Bidders	-0.016***	-0.020***	-0.027***	-0.024***
	(0.006)	(0.006)	(0.003)	(0.004)
Distance to the Project Location	-0.004	-0.014	-0.009	0.017
	(0.022)	(0.031)	(0.018)	(0.021)
Rival's Minimum Distance to	-0.019	0.021	-0.022	-0.015
the Project Location	(0.030)	(0.034)	(0.028)	(0.030)
Top Firm	-0.036	-0.024	-0.043*	-0.085***
	(0.029)	(0.038)	(0.026)	(0.032)
Local Market Power	-0.105***	-0.083***	-0.062***	-0.055**
	(0.028)	(0.031)	(0.024)	(0.025)
Debt to Asset Ratio	-0.089*	-0.126	-0.025	0.137*
	(0.048)	(0.094)	(0.041)	(0.081)
Debt to Asset Ratio* Top Firm	-0.165	-1.320	-0.167	-1.302
	(0.357)	(1.173)	(0.254)	(0.914)
Elevation	0.002	0.002	0.005**	0.004*
	(0.003)	(0.003)	(0.002)	(0.002)
Log of Firm's Backlog	0.002	0.002	0.001	0.003**
	(0.001)	(0.002)	(0.001)	(0.001)
Log of Rival's Minimum Backlog	-0.002	-0.003*	-0.002*	-0.002*
	(0.001)	(0.002)	(0.001)	(0.001)
Average Number of Building	-0.006	-0.005	-0.008	-0.009
Permits	(0.009)	(0.009)	(0.006)	(0.005)
Unemployment Rate	-0.044***	-0.033***	-0.009	-0.013*
	(0.011)	(0.010)	(0.007)	(0.007)
Asphalt Project	0.051	0.003	0.062*	0.014
	(0.049)	(0.049)	(0.033)	(0.031)
Bridge Project	0.084	-0.020	0.066**	-0.034
	(0.051)	(0.049)	(0.031)	(0.031)
Time Dummy	Yes	Yes	Yes	Yes
Firm Fixed Effects (55)	No	Yes	No	Yes
Item Fixed Effects (709)			Yes	Yes
Observations	846	846	50,465	50,465

*** Denotes statistical significance at the 1% level, ** denotes significance at the 5% and * denotes significance at the 10% level. Clustered standard errors are in parentheses.

are statistically significant determinant of bids at the project level. Meanwhile, the coefficient on the ex post price adjustment amount is negative and statistically significant. Firms bid more aggressively when there is a price adjustment mechanism in place. The evidence is consistent with Kosmopoulou and Zhou (2014), who postulate that price adjustment clauses that are based on an index may produce direct cost savings to state agencies. With no price adjustment in place, bidders are exposed to the risk of unanticipated changes in the cost of major inputs, increasing their bids to reduce risk exposure in long-term contracts. If these effects are not controlled for, the results are likely to be biased, because anticipation of quantity adjustments is expected to be correlated with whether a price adjustment clause is in place.

In columns 3-4, we estimate a model for bids at the item level, rather than project level, while controlling for item effects. The model estimated in column (3) does not include firm fixed effect and the model estimated in column (4) does. The evidence for a relationship between change orders and itemized bidding is very strong, as both the economic and statistical significance of the five change order variables is substantial. The fact that the itemized regressions are picking up stronger effects than what are observed at the project level suggests that firms may have manipulated their bids in such a way that has a limited impact on the overall level of their bids to remain competitive, but may maximize the opportunity for ex post profits.

Insofar as the other variables, the engineering cost estimate and the log of calendar days have the expected impact on the bid. In particular, the engineer cost estimates explain almost all of the variation in our dependent variables. As Tadelis (2012) recently argued, more complex projects are expected to experience ex post renegotiations in fixed price contracts due to contractual incompleteness.[11] Bidders are more likely to incorporate a premium for ex

[11]Since the number of items in a project and the number of calendar days both represent measures of project complexity we performed a join F test of the significance of these variables. We report the p-value at 0.000.

post uncertainty or engineering error into their bids. The impact of the expected number of bidders is consistent with our expectation. Increased level of competition causes bidders to bid more aggressively. Among the variables controlling for the relative strengths of bidders and rivals, we find that firms with significant local market power bid more aggressively. This result suggests that project location is one of the critical determinants of bidding. The estimated effect of the debt to asset ratio at the project level is negative contrary our expectations that financially constrained firms will bid less aggressively. The results, however, become statistically insignificant when we add firm effects.

Bidding behavior can be affected by business cycle fluctuations. Bidders bid more aggressively when faced with a high unemployment rate, which indicates a decline in economic activity. Bids can be low and more competitive during recessions and higher during expansions. Intuitively, the opportunity cost of losing a contract is much higher for firms during a recession while they are more likely to seek higher profit margins when more opportunities for work become available.

The bidding model described in equation (1) relies on a linear specification of the bids on a set of observable project and bidder characteristics, and measures of economic fluctuation. We can gain a deeper insight into the mechanisms behind change orders by assuming that the observed bids are the Bayesian Nash Equilibria of the theoretical model. Then we adopt a structural approach that is used to recover the latent primitives of the auction model. In order to examine the impact of contract renegotiation on strategic bidding, it is crucial to control for the competitive environment and project heterogeneity associated with contract renegotiation. The next section employs structural approaches that will allow us to control for competition while relaxing the assumptions behind equation (1) generating estimates of the latent cost distributions for projects with or without renegotiations.

We begin with the observation, corroborated by our discussions with highway construction engineers, that firms can make predictions about change orders and these predictions

Table 3: Probabilities of renegotiation for pay items

Group of Items	Pay Items	Full Sample			Project Values between $200,000 and $5 million		
		Probability	Number of Occurrences	Number of Change Orders	Probability	Number of Occurrences	Number of Change Orders
Top 5	490.30	0.294	85	25	0.290	69	20
	406.25	0.256	82	21	0.250	72	18
	630.15	0.192	260	50	0.206	218	45
	406.27	0.171	35	6	0.176	34	6
	301.35	0.162	68	11	0.125	56	7
Bottom 5	529.20	0.000	71	0	0.000	68	0
	621.21	0.000	91	0	0.000	82	0
	631.17	0.000	220	0	0.000	199	0
	208.35	0.000	36	0	0.000	33	0
	620.70	0.000	68	0	0.000	59	0

The top 5 and bottom 5 items above are those with the highest (lowest) probability of positive quantity adjustments among items that appear most frequently in projects, specifically those in the top quintile of overall item frequencies. The last three columns restrict attention to the probability of renegotiation of projects between $200,000 and $5 million, creating a subsample of projects of size similar to the ones considered in Section 3.3.

effectively assign probabilities to various outcomes. Thus, a key assumption in our model is that bidders make predictions about change orders on specific items based not only upon project characteristics, but also upon the historical frequency with which items have been negotiated. It is immediately apparent that to compare projects and items with and without renegotiation, as shown in the next sections, we require that the ex-post probability of renegotiation for selected items is not one. Table 3 offers evidence on the ex-post probability that an item is renegotiated considering the 712 items we have in our sample of 50,465 observations. Because it is naturally impossible to report on the frequencies for all tasks considered in our sample of projects, we rank the items by their likelihood of positive quantity adjustment and present the top 5 and bottom 5 items.[12] For instance, the task associated with

[12]The pay item description for the items presented in Table 3 is the following: 490.30: Superpave Bituminous Concrete Pavement, 406.25: Bituminous Concrete Pavement, 630.15: Flaggers, 406.27: Medium Duty Bituminous Concrete Pavement, 301.35: Subbase of Dense Graded Crushed Stone, 529.20: Partial Removal of Structure, 621.21: HD Steel Beam Guardrail, Galvanized, 631.17: Testing Equipment, Bituminous, 208.35: Cofferdam Excavation, Rock and 620.17: Gate for Chain-Link Fence, 2.4 m (8 feet).

Superpave Bituminous Concrete Pavement, or item 490.30, has roughly 1/3 chance of being renegotiated, while work on installing Galvanized Steel Beam Guardrail, or item 631.17, has not been renegotiated despite the fact that it is frequently included in the project plans. These data are indicative of the overall pattern: while some items tend to be included in change orders only very rarely, if ever, other items are renegotiated in approximately one out of every four projects in which they are included. Thus, a contractor, who has been participating in procurement auctions, might incorporate these expectations into their bidding behavior. Indeed, in our own discussions with private contractors and state engineers, they confirm that they are keenly aware of the past pattern of change orders on particular items and types of projects. This crucial aspect is incorporated in the model developed in Section 3.1.

3 Structural estimation

In this section, we develop a bidding framework by assuming an independent private value (IPV) model with asymmetric bidders, which is closely related to the previous literature such as Bajari and Ye (2003), Campo, Perrigne, and Vuong (2003), and Bajari, Houghton, and Tadelis (2014). In the case of asymmetric bidders, the distributions of costs vary by bidder, as opposed to the case of symmetric bidders in which private cost estimates are assumed to be independently and identically distributed (*i.i.d.*). The asymmetries may arise from different capacity constraints, distances to work sites, cost efficiency levels, or work experience. In this setting, we are able to express each bidder's inverse bid function as a function of his rivals' bid distributions and obtain the cost of bidding in projects with renegotiations as well as the cost of bidding in projects without renegotiations. We then employ nonparametric estimation methods similar to the ones in Guerre, Perrigne, and Vuong (2000), Haile, Hong, and Shum (2006), and Bajari, Houghton, and Tadelis (2014) to uncover cost distributions.

Lastly, we offer a series of counterfactual exercises to investigate the effect of renegotiations and strategic bidding behavior.

3.1 Equilibrium bidding behavior

As we have stated, a key assumption is that bidders have prior probabilistic beliefs regarding the likelihood of renegotiations. This assumption structures bidders' assessment of their expected profits, from which we derive their equilibrium bidding functions. Then, we estimate bidders' latent cost distributions using their observed bids and equilibrium bidding functions.

Consider a bidding function that is continuously differentiable and strictly increasing in cost. A project consists of a list of tasks, $t = 1, \ldots, T$. By letting b_t^i indicate bidder i's unit price on an item t, we define a bid price vector as $\mathbf{b}^i = (b_1^i, \ldots, b_T^i)$. The estimated quantity for each task t is q_t^e and its actual quantity used to complete the task is denoted as q_t^a. In vector notation they are $\mathbf{q}^e = (q_1^e, \ldots, q_T^e)$ and $\mathbf{q}^a = (q_1^a, \ldots, q_T^a)$ respectively. Let $s^i = \sum_{t=1}^{T} b_t^i q_t^e = \mathbf{b}^i \cdot \mathbf{q}^e$ be the vector product of unit prices and estimated quantities. In low price sealed bid auctions, a bidder i wins a contract if he/she submits a bid that is the lowest, i.e., $\mathbf{b}^i \cdot \mathbf{q}^e < \mathbf{b}^j \cdot \mathbf{q}^e$, $\forall i \neq j$. Then, if bidder i bids s^i, the probability that his bid is greater than j's is defined as $H_j(s^i) \equiv \text{pr}(\mathbf{b}^i \cdot \mathbf{q}^e > \mathbf{b}^j \cdot \mathbf{q}^e)$. Finally, $\prod_{j \neq i}(1 - H_j(s^i))$ is defined as the probability that bidder i wins the auction with s^i.

Unlike Bajari, Houghton, and Tadelis (2014) who assume bidders have perfect foresight over actual quantities, we assume that bidders know that the specification about an item is incomplete or has an error, and that additional work may be necessary. In our model bidders form expectations about future adjustments on each item based on its historical frequency of renegotiation. A breakdown of items by the probability of renegotiation, k, includes two types of items: items that are not renegotiated ($k_t = 0$), and items that are renegotiated ($k_t > 0$). With probability k_t the specification about an item is incomplete or contains an error, while with probability (1 - k_t) the original specification or plan accurately describes the task.

We define bidder i's expected profit function as follows:

$$\pi^i(\mathbf{b}^i, \mathbf{c}^i, \mathbf{k}) = \left[\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot (\mathbf{k} \cdot \mathbf{q}^a + (\mathbb{1} - \mathbf{k}) \cdot \mathbf{q}^e) - \mathbf{k}\tau \cdot (\mathbf{q}^a - \mathbf{q}^e)\right] \times \left[\text{pr}\left(\mathbf{b}^i \cdot \mathbf{q}^e < \mathbf{b}^j \cdot \mathbf{q}^e\right)\right]$$
$$= \left[\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot (\mathbf{k} \cdot \mathbf{q}^a + (\mathbb{1} - \mathbf{k}) \cdot \mathbf{q}^e) - \mathbf{k}\tau \cdot (\mathbf{q}^a - \mathbf{q}^e)\right] \times \left[\prod_{j \neq i}(1 - H_j(s^i))\right], \tag{2}$$

where the vector $\mathbb{1}$ is a T-dimensional vector of ones, $\mathbf{c}$ represents production costs and τ adaptation costs. Note that the profit function of the ith firm is equal to the expected markup times the probability that firm i is the lowest bidder. The first order condition (FOC) is equal to:

$$\frac{\partial \pi^i(\mathbf{b}^i, \mathbf{c}^i, \mathbf{k})}{\partial b_t^i} = (\mathbf{k} \cdot \mathbf{q}^a + (\mathbb{1} - \mathbf{k}) \cdot \mathbf{q}^e) \left[\prod_{j \neq i}(1 - H_j(s^i))\right] - \left[\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot (\mathbf{k} \cdot \mathbf{q}^a + (\mathbb{1} - \mathbf{k}) \cdot \mathbf{q}^e)\right.$$
$$\left. - \mathbf{k}\tau \cdot (\mathbf{q}^a - \mathbf{q}^e)\right] \times \left[q_t^e \sum_{k \neq i} h_k(s^i) \prod_{j \neq i,k} (1 - H_j(s^i))\right] = 0. \tag{3}$$

Since $\left[q_t^e \sum_{k \neq i} h_k(s^i) \times \prod_{j \neq i,k} (1 - H_j(s^i))\right]$ is equal to $\frac{\partial s^i}{\partial b_t^i} \times \frac{\partial \left[\prod_{j \neq i}(1 - H_j(s^i))\right]}{\partial s^i}$ as shown in the Appendix B, we write the first order condition as,

$$\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot (\mathbf{k} \cdot \mathbf{q}^a + (\mathbb{1} - \mathbf{k}) \cdot \mathbf{q}^e) - \mathbf{k}\tau \cdot (\mathbf{q}^a - \mathbf{q}^e) = \left(\frac{k_t q_t^a + (1 - k_t) q_t^e}{q_t^e}\right) \left(\sum_{j \neq i} \frac{h_j(s^i)}{(1 - H_j(s^i))}\right)^{-1}. \tag{4}$$

Equation (4) expresses the FOC as a function of the probability, k_t, that item t is renegotiated. If $k_t = 0$ for all tasks t, then equation (4) can be written as follows:

$$(\mathbf{b}^i - \mathbf{c}^i) \cdot \mathbf{q}^e = \left(\sum_{j \neq i} \frac{h_j(s^i)}{(1 - H_j(s^i))}\right)^{-1}. \tag{5}$$

On the other hand, if $k_t > 0$, the equation is expressed as follows:

$$(\mathbf{b}^i - \mathbf{c}^i) \cdot \tilde{\mathbf{q}}^a - \tau\left(\tilde{\mathbf{q}}^a - \mathbf{q}^e\right) = \left(\frac{k_t q_t^a + (1-k_t)q_t^e}{q_t^e}\right)\left(\sum_{j \neq i} \frac{h_j(s^i)}{(1 - H_j(s^i))}\right)^{-1} \tag{6}$$

where the vector $\tilde{\mathbf{q}}^a = \mathbf{k}(\mathbf{q}^a - \mathbf{q}^e) + \mathbf{q}^e$ represents a weighted average of actual and estimated quantities. In the next sections, we uncover the latent cost distributions in the case of positive quantity adjustments, $\tilde{q}_t^a > q_t^e$ for at least one task t.

3.2 Nonparametric estimation

This section follows closely Bajari, Houghton, and Tadelis (2014), Haile, Hong, and Shum (2006) and De Silva, Dunne, Kosmopoulou, and Lamarche (2012) to estimate the equilibrium bidding functions for projects with and without renegotiation. We employ a nonparametric approach that allows one to directly control for auction heterogeneity in the first step of the two-step procedure.

Let $r = \{0, 1\}$ denote projects without ex post renegotiation and with ex post renegotiation. We first estimate a reduced form regression while controlling for auction-specific and bidder-specific characteristics,

$$y_{rj}^{(m_r)} \equiv \mathbf{b}_{rj}^{(m_r)} \cdot \mathbf{q}^{e(m_r)} = \boldsymbol{\mu}_r' \mathbf{x}_{rj}^{(m_r)} + \boldsymbol{\theta}_r' \mathbf{z}^{(m_r)} + \varepsilon_{rj}^{(m_r)}, \tag{7}$$

where the dependent variable $y_{rj}^{(m_r)}$ is a project bid amount by contractor j in an auction m_r. The vector $\mathbf{x} \in \mathcal{X} \subset R^{p_x}$ includes controls for a firm's distance and its rival's minimum distance to the work site, the indicator variable for a top firm, and firm fixed effects to control for unobserved bidder heterogeneity in the first step of the structural estimation. The variable $\mathbf{z} \in \mathcal{Z} \subset R^{p_z}$ controls for auction-specific effects by including ex post price adjustment amounts, new added item amounts, dropped item amounts, log of calendar days, complexity, number of bidders, and engineer's cost estimate.[13,14]

Recall that $s^i = \mathbf{b}^i\mathbf{q}^e$ and that the cumulative distribution function of contractor j is defined as $H_j(s^i) \equiv Pr(\mathbf{b}_j\mathbf{q}^e \leq s^i)$. Using equation (7) and substituting the contractor j's bid in the cumulative distribution function, we obtain that the probability that bidder i's bid is greater than bidder j's bid is:

$$H_{rj}^{(m_r)}(b) = Pr\left(\boldsymbol{\mu}_r'\mathbf{x}_{rj}^{(m_r)} + \boldsymbol{\theta}_r'\mathbf{z}^{(m_r)} + \varepsilon_{rj}^{(m_r)} \leq s_r^i\right) \equiv G\left(b_{rj}^{(m_r)}\right), \tag{8}$$

where $b_{rj}^{(m_r)} = s_r^i - \boldsymbol{\mu}_r'\mathbf{x}_{rj}^{(m_r)} - \boldsymbol{\theta}_r'\mathbf{z}^{(m_r)}$. Under i.i.d. assumptions on the error term ε, we estimate equation (7) using standard parametric models, obtain the residuals, $\widehat{\varepsilon}_{rj}^{(m_r)}$, and use $\widehat{\varepsilon}_{rj}$ to estimate the density and bid distribution for projects without ex post renegotiation ($r = 0$) and with ex post renegotiation ($r = 1$), denoted by $h_{rj}(\cdot)$ and $H_{rj}(\cdot)$ respectively.[15] We obtain $\widehat{h}_{rj}$ and $\widehat{H}_{rj}$ considering a continuously differentiable kernel function defined over a compact support and a properly chosen bandwidth. We use a triweight kernel to estimate the density and distribution functions, $K(u) = (35/32)(1-u^2)^3 1\{|u| \leq 1\}$, and we select the bandwidth using the form $w_r = \kappa\hat{\sigma}(\widehat{\varepsilon}_{rj}^{(m_r)})(n_r L_{rj})^{-1/6}$, where $\sigma(\widehat{\varepsilon}_{rj}^{(m_r)})$ is defined as the standard deviation of $\widehat{\varepsilon}_{rj}^{(m_r)}$, $\kappa = 2.99 \times 1.06$, and L_{rj} represents the number of auctions in which bidder j participated.

[13]We omit a description of an alternative specification that included four additional variables: local market power, debt/asset ratio, elevation and unemployment. The results are similar to the ones presented in Table 5, and therefore, we offer results based on a more parsimonious model (7). This specification include variables that are similar to the ones employed in Bajari, Houghton, and Tadelis (2014).

[14]The results from estimating equation (7) were similar to the results presented in Table A.2's column (2). Consequently, they are omitted to save space but they are available upon request. As expected, the effect of complexity and the logarithm of calendar days were significant in projects with renegotiations and insignificant in projects without renegotiations. The other estimated effects were insignificant with the exception of the engineer's cost estimate.

[15]It is interesting to observe that the parametrization of the model used in equation (7) can be associated with differences in the estimated cumulative distribution function of contractor j. Although it seems natural to estimate H separately for projects with and without renegotiations, we implemented a variation of the model imposing that $\boldsymbol{\mu}_0 = \boldsymbol{\mu}_1 = \boldsymbol{\mu}$ and $\boldsymbol{\theta}_0 = \boldsymbol{\theta}_1 = \boldsymbol{\theta}$. We found that the results shown in the next section are not sensitive to the parametrization used in equation (7) (e.g., the median markup for projects with and without negotiations were quantitatively and qualitatively similar to the ones reported below in Table 5).

Lastly, after estimating the density function, we are able to uncover the cost distributions by solving the following two equations in terms of the unknown costs,

$$(\mathbf{b}_0^i - \mathbf{c}_0^i) \cdot \mathbf{q}^e = \left(\sum_{j \neq i} \frac{\hat{h}_{0j}(s^i)}{(1 - \hat{H}_{0j}(s^i))} \right)^{-1} \tag{9}$$

$$(\mathbf{b}_1^i - \mathbf{c}_1^i) \cdot \hat{\mathbf{q}}^a - \tau \left(\hat{\mathbf{q}}^a - \mathbf{q}^e \right) = \left(\frac{\hat{k}_t q_t^a + (1 - \hat{k}_t) q_t^e}{q_t^e} \right) \left(\sum_{j \neq i} \frac{\hat{h}_{1j}(s^i)}{(1 - \hat{H}_{1j}(s^i))} \right)^{-1} \tag{10}$$

where $\hat{k}_t$ is an estimate of the probability of renegotiation and $\hat{\mathbf{q}}^a = \hat{\mathbf{k}}(\mathbf{q}^a - \mathbf{q}^e) + \mathbf{q}^e$. As in Table 3, we construct the historical probability of positive quantity adjustment on a particular item by dividing the number of occurrences of such adjustment with the number of occurrences on the original contracts. The solution of equations (9) and (10) represents pseudo-values of the costs of projects without and with ex post renegotiations, respectively.

The estimation of equations (9) and (10) requires a subset of projects that have a relatively similar set of tasks and fit the IPV model. We restrict our attention to road/highway projects with two or three bidders based on frequency. As De Silva, Dunne, Kankanamge, and Kosmopoulou (2008) discuss in detail, the individual bidder's efficiency level is more critical to determine its cost in asphalt projects. Bidders can estimate their costs for asphalt projects more accurately than those for bridge projects, which are typically studied in a common value setting (see also Hong and Shum (2002)).[16]

Although equations (9) and (10) focus on item t, it is conceivable that there are auctions that fit the IPV framework and have other items with change orders. It is convenient then

[16] In fact, in column (1) of Table A.2 we estimated a reduced form model using a single change order indicator rather than the individual change order variables to examine systematic differences in bidding patterns between projects that have ex post renegotiations and those that do not. The results show that there are indeed differences in bidding, naturally raising a concern about the possibility of a type of selection bias in the structural analysis. In contrast to our results using the full sample, when we estimate the model using only the subsample of homogeneous projects that will be used in structural estimation the indicator variable of a change order is no longer statistically significant. This result is consistent with the view that in the subsample change orders are randomly assigned conditional on observable covariates. Other selection issues are addressed in Section 3.6.

Table 4: Comparison of summary statistics across projects

	Positive Quantity Adjustment ($\mathcal{S}_R$)					No Quantity Adjustment					
	Obs	Mean	Std	Min	Max	Subset	Obs	Mean	Std	Min	Max
Bid Amount	72	\$2.094	\$1.230	\$0.244	\$4.918	$\mathcal{S}_A$	69	\$1.207	\$1.012	\$0.220	\$4.870
						$\mathcal{S}_B$	37	\$1.082	\$0.987	\$0.242	\$4.870
Engineer Cost	72	\$2.160	\$1.342	\$0.254	\$4.754	$\mathcal{S}_A$	69	\$1.243	\$1.077	\$0.214	\$4.908
						$\mathcal{S}_B$	37	\$1.124	\$1.042	\$0.214	\$4.908
Relative Bid	72	1.028	0.239	0.627	1.676	$\mathcal{S}_A$	69	1.031	0.208	0.729	1.723
						$\mathcal{S}_B$	37	0.993	0.156	0.729	1.457
Complexity	72	60.972	27.860	6.000	118.000	$\mathcal{S}_A$	69	45.855	25.727	5.000	105.000
						$\mathcal{S}_B$	37	45.162	24.790	16.000	105.000
Calendar Days	72	145.556	77.663	56.000	378.000	$\mathcal{S}_A$	69	105.304	47.842	30.000	231.000
						$\mathcal{S}_B$	37	95.189	51.229	30.000	231.000
Number of Bidders	72	2.486	0.503	2.000	3.000	$\mathcal{S}_A$	69	2.638	0.484	2.000	3.000
						$\mathcal{S}_B$	37	2.622	0.492	2.000	3.000

All monetary figures are expressed in millions of dollars.

to define three subsets of projects that corresponds to these equations. We denote the subsets by $\mathcal{S}_R$, $\mathcal{S}_A$, and $\mathcal{S}_B$. Let m denote an auction and t a task. The subset of interest is $\mathcal{S}_R = \{(m_{\mathcal{R}}, t) : q_t^a > q_t^e,\ (m_{\mathcal{R}}, t) \in \mathcal{A}_R \times \mathcal{T}\}$, where $\mathcal{A}_R$ is a set that includes road/highway contracts with positive quantity adjustments and $\mathcal{T}$ represents a set of tasks. The subset of projects that were not renegotiated is $\mathcal{S}_A = \{(m_{\mathcal{A}}, t) : q_t^a = q_t^e,\ \forall (m_{\mathcal{A}}, t) \in \mathcal{A}_A \times \mathcal{T}\}$, where $\mathcal{A}_A$ includes projects in which there is no positive quantity adjustment although it contains other change orders (e.g., new added item adjustments and dropped items). Finally, we define an alternative subset of non-renegotiated projects $\mathcal{S}_B = \{(m_{\mathcal{B}}, t) : q_t^a = q_t^e,\ \forall (m_{\mathcal{B}}, t) \in \mathcal{A}_B \times \mathcal{T}\}$, where $\mathcal{A}_B$ contains projects with no renegotiation at all. Because our empirical strategy relies on identifying a set of tasks in projects with and without renegotiation, it is important to note that the set of tasks $\mathcal{T}$ is identical in $\mathcal{S}_R$, $\mathcal{S}_{\mathcal{A}}$ and $\mathcal{S}_{\mathcal{B}}$.

The descriptive statistics for these three groups are presented in Table 4. We restrict attention to projects with an estimated cost between \$200,000 and \$5 million, roughly excluding the largest and smallest 10% of road/highway projects to achieve greater homogeneity across groups. As shown by the table, the more complex a project is, the more likely it will be renegotiated. This essentially implies that long and more complex projects are renegotiated with higher frequency. The issue of auction heterogeneity is known to affect the quality of statistical inferences and consequently it is addressed by the estimation procedure described in the previous sections which follows closely Guerre, Perrigne, and Vuong (2000), Haile, Hong, and Shum (2006), and Bajari, Houghton, and Tadelis (2014). By restricting our attention to these sets of projects, and controlling for other sources of heterogeneity, our quasi-experimental strategy yields estimates of markups and costs that are free of bias and simple to interpret.

3.3 Estimation results for project costs and markups

Figure 2 shows the estimated relative project cost distributions for projects with and without renegotiations. The densities presented in the figures are obtained using the project pseudo costs divided by their corresponding engineering cost estimates to control for different project values. The solid line indicates the project cost estimates for renegotiated projects while the dotted line is the project cost estimates for projects that were not renegotiated. Notice that the two panels are distinguished by the comparison group employed to estimate $\mathbf{c}_0$. The left panel presents the estimated cost densities of projects without renegotiations with the exception of new added item adjustments and dropped items ($\mathcal{S}_A$) and the right panel presents the estimated cost densities of projects with no renegotiation at all ($\mathcal{S}_B$). While the relative project cost estimates are not statistically different, the level of the estimated costs for the projects with renegotiations is significantly higher than those without renegotiations. In the sample, costs are more or less increasing in proportion to the unit quantity estimates and there are no statistically significant scale effects and/or adaptation costs evident at the project level. To further substantiate this, we calculated Kolmogorov-Smirnov (KS) statistics to test the hypotheses that the cost distribution of projects with renegotiation was the same

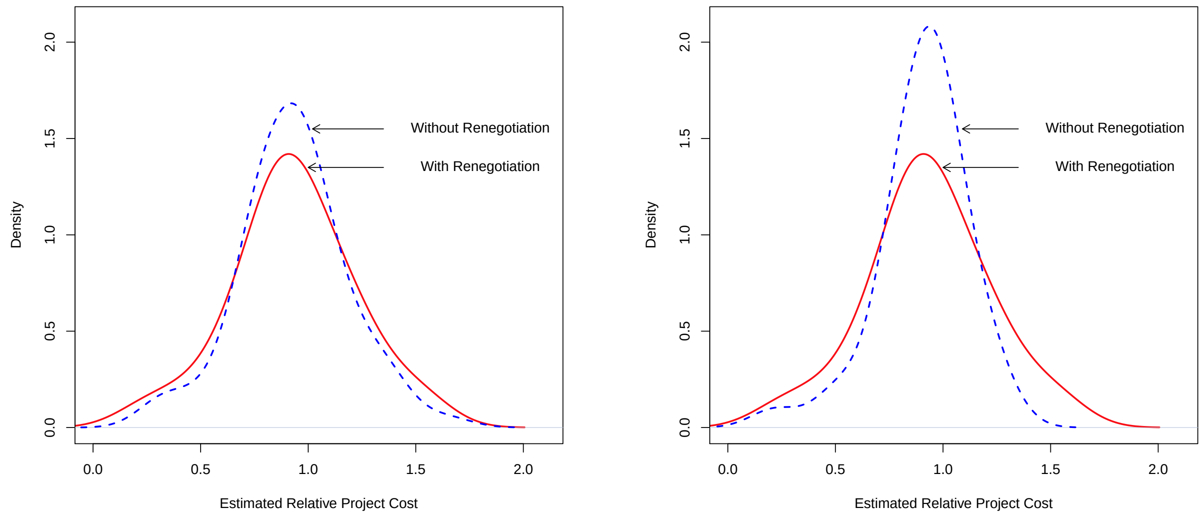

Figure 2: Relative cost in projects with and without renegotiation using subsets $\mathcal{S}_A$ (left panel) and $\mathcal{S}_B$ (right panel)

as the cost distribution of either $\mathcal{S}_A$ or $\mathcal{S}_B$. In both tests, we failed to reject the null.[17]

With our project-level cost estimates in hand, we now proceed to the analysis of markups. Markups over production costs could be associated with the risk premium for project uncertainty and rents obtained by strategic bidding adjustments consistent with asymmetries in experience and level of efficiency. Bajari (2001) shows that markups decrease as the number of bidders increases. Bajari and Ye (2003) find that estimated markups are consistently higher in the collusive models than in the competitive model, showing that they are around 3 to 4% depending on the precise level of competition. Recently, Bajari, Houghton, and Tadelis (2014) estimated firms' markups on California highway projects. In the standard (mis-specified) model that ignores ex post renegotiations and adaptation costs, they estimate markups of 3.7%. After accounting for the direct costs and revenues of change orders, the estimates rise to 8.1%, but when adaptation costs are included markups are estimated

[17]The difference was about 2% at the mean level. The p-values for the K-S tests were 0.860 and 0.490 respectively.

Table 5: Markups for projects with and without renegotiation

	Percentile						
Subset	20%	30%	40%	50%	60%	70%	80%
With Renegotiation ($\mathcal{S}_R$)	2.574	4.564	7.114	8.840	12.080	15.440	19.700
Without Renegotiation ($\mathcal{S}_A$)	2.374	3.352	4.350	6.050	8.468	10.840	15.120
Without Renegotiation ($\mathcal{S}_B$)	1.702	2.330	3.562	4.610	7.252	8.738	11.760

at only 3.8%, nearly identical to results in the naive model. Clearly proper consideration of renegotiations and change orders is vital to the correct determination of markups. Our approach estimates all costs associated with change orders - both direct and adaptation - but does not decompose them.

In Table 5, we summarize our estimates of bidders' markups over estimated costs for projects with and without positive quantity renegotiations.[18] We report results between 0.2 and 0.8 quantiles of the distributions to avoid interpreting results from potentially biased estimates at the tails. We find that bidders achieve higher markups in projects when renegotiation is anticipated. Furthermore, the estimated median markups are similar to those reported in Bajari, Houghton, and Tadelis (2014). The estimated median markups are 8.84% under ex post renegotiation, and they are systematically higher than those in contracts with no renegotiation. The estimated markups for the projects without renegotiation are higher than those reported in Bajari, Houghton, and Tadelis (2014). A possible reason could be that the road construction market is highly concentrated in the state of Vermont with the top two firms winning 1/3 of total projects during the sample period. In addition, our estimated effects are distinguished from potential price adjustments, which are confounded in prior estimates in the literature. Table 5 suggests a 3-4 percentage point difference at the median level between markups in contracts with and without renegotiation.

[18] To estimate equation (7), as explained before, we include contractor heterogeneity to control for unobserved bidder effects. Moreover, we based our comparison on similar projects and identical items to implicitly control for item heterogeneity. Krasnokutskaya (2011) points out that the estimated average markups could be considerably higher when failing to control for unobserved heterogeneity.

Table 6: Project markups for projects with renegotiation under different assumptions about expectations of change orders

	Percentile						
Expectations	20%	30%	40%	50%	60%	70%	80%
$0 < k < 1$	2.574 (1.042) [1.381, 5.460]	4.564 (1.564) [1.973, 8.041]	7.114 (1.943) [2.788, 10.012]	8.840 (2.340) [3.680, 12.503]	12.080 (2.970) [4.898, 16.081]	15.440 (3.589) [6.518, 19.801]	19.700 (4.638) [8.721, 26.522]
$k = 1$	3.120 (1.123) [1.589, 5.880]	4.868 (1.713) [2.180, 9.022]	7.710 (2.179) [3.144, 11.440]	9.515 (2.705) [4.300, 14.651]	15.800 (3.465) [5.771, 19.122]	18.580 (4.302) [7.471, 24.181]	27.100 (5.807) [9.788, 32.622]

Mean values are reported.

Our estimates are produced from a strategic bidding model in which firms maximize profits based on the expectations of change orders. Those expectations are based upon the historical frequency of change orders. In contrast, Bajari, Houghton, and Tadelis (2014) model imposes perfect foresight, in which firms know in advance, with certainty, the actual item quantities. In the notation of our model, that corresponds to $k = 1$. As a basis for comparison, we estimated markups using their assumption in our dataset. In Table 6, we present estimates of markups under these two sets of expectations. The estimates under our modeling assumption are denoted by $0 < k < 1$, and the estimates under theirs are denoted by $k = 1$. The markups for $k = 1$ are slightly higher than under our assumption. However, the p-value on the Kolmogorov-Smirnov test of the invariance of markup distributions is 0.71, meaning that we fail to reject the hypothesis that the markup distributions are identical. Thus, the evidence that markups are higher on projects with renegotiations is robust to different assumptions about how firms anticipate change orders. In order to investigate the reasons for these increased markups, we now turn to the estimation of itemized costs.

3.4 Estimation of itemized costs

In comparing bid distributions of projects with and without renegotiations, item heterogeneity is a challenging issue. Since projects can include more than one renegotiated item, we restrict attention to projects in which, at most, one item is renegotiated with positive quantity adjustment. We identified the six renegotiated items in this process, as shown in Table 7, and focus on their cost estimates or their markups at the itemized level.[19] Those items that have positive quantity adjustments in the subset $\mathcal{S}_R$ are denoted by $\mathcal{I}_R$. Then, we select the same tasks from the subsets of projects without renegotiation, $\mathcal{S}_A$ and $\mathcal{S}_B$. Let

[19] The pay item description for these six items is the following: 406.25: Bituminous Concrete Pavement, 490.30: Superpave Bituminous Concrete Pavement, 617.10: Relocate Mailbox, Single Support, 621.90: Temporary Traffic Barrier, 630.15: Flaggers and 646.85: Removal of Existing Pavement Marking. Notice that these items frequently occur on a contract and are more frequently renegotiated during the sample period.

$\mathcal{I}_A$ and $\mathcal{I}_B$ denote subsets that include these items. As an illustrative example, while item 406.25 had a positive quantity adjustment in 5 bids included in the subset $\mathcal{S}_R$, this item was not renegotiated in 15 bids in the subset $\mathcal{S}_A$ and 12 bids in the subset $\mathcal{S}_B$. Notice that the itemized bid prices are similar among these groups while the itemized bid amounts, which are the itemized bid prices multiplied by the estimated quantities are significantly different across items between the subsamples.

Table 7: Comparison of summary statistics for pay items

			Bid Price (in $)				Itemized Bid Amount (in $10000)			
Pay Items	Subset	Probability	Mean	Std	Min	Max	Mean	Std	Min	Max
	$\mathcal{I}_R$		$62.64	$8.50	$52.52	$70.00	$99.91	$32.67	$58.30	$133.00
406.25	$\mathcal{I}_A$	0.25	$91.48	$33.91	$49.00	$168.00	$17.12	$12.61	$2.72	$39.90
	$\mathcal{I}_B$	(0.44)	$84.10	$28.93	$49.00	$138.00	$20.43	$11.92	$8.13	$39.90
	$\mathcal{I}_R$		$79.31	$38.23	$42.00	$165.00	$141.48	$81.30	$25.34	$313.43
490.30	$\mathcal{I}_A$	0.29	$72.59	$19.53	$44.50	$110.00	$80.09	$47.61	$27.00	$187.40
	$\mathcal{I}_B$	(0.46)	$72.57	$19.14	$44.50	$110.00	$79.60	$59.33	$27.00	$187.40
	$\mathcal{I}_R$		$230.83	$80.48	$142.50	$300.00	$0.02	$0.01	$0.01	$0.03
617.10	$\mathcal{I}_A$	0.07	$177.50	$59.81	$120.00	$250.00	$0.04	$0.02	$0.02	$0.08
	$\mathcal{I}_B$	(0.22)	$160.00	$61.64	$120.00	$250.00	$0.05	$0.02	$0.04	$0.08
	$\mathcal{I}_R$		$62.50	$31.82	$40.00	$85.00	$0.38	$0.19	$0.24	$0.51
621.90	$\mathcal{I}_A$	0.07	$40.20	$18.71	$20.00	$66.00	$3.91	$2.34	$1.40	$6.93
	$\mathcal{I}_B$	(0.26)	$22.50	$3.54	$20.00	$25.00	$1.58	$0.25	$1.40	$1.75
	$\mathcal{I}_R$		$30.59	$14.49	$22.50	$56.45	$6.72	$4.36	$3.38	$14.11
630.15	$\mathcal{I}_A$	0.19	$20.87	$10.74	$1.00	$63.00	$3.20	$3.72	$0.05	$17.55
	$\mathcal{I}_B$	(0.39)	$19.87	$11.51	$1.00	$63.00	$2.08	$2.57	$0.05	$11.37
	$\mathcal{I}_R$		$0.67	$0.11	$0.59	$0.75	$1.70	$0.29	$1.49	$1.90
646.85	$\mathcal{I}_A$	0.06	$2.03	$1.41	$0.30	$5.00	$0.93	$1.72	$0.01	$5.70
	$\mathcal{I}_B$	(0.25)	$1.97	$1.21	$0.70	$5.00	$0.76	$1.80	$0.01	$5.70

Standard errors are in parentheses.

It is well known in the empirical auction literature there is no analytical solution for the bidding strategies in an IPV setting with asymmetric bidders. It is also known and immediately apparent in Table 7 that item heterogeneity is a crucial determinant of whether an item is renegotiated. An empirical identification strategy that fails to address it cannot offer credible evidence on the effect of renegotiation on bidding patterns and costs. Under the assumption that the share of an item in a project's bid is proportional to the share of an item in a project's cost in nonrenegotiated contracts, this section shows that it is possible to uncover itemized costs while addressing item heterogeneity.

We begin by rewriting equation (5) for projects with $k_t = 0 \;\forall t$ as,

$$\mathbf{c}_0^i \cdot \mathbf{q}_0^e = \mathbf{b}_0^i \cdot \mathbf{q}_0^e - \left(\sum_{j \neq i} \frac{h_{0,j}(s_0^i)}{(1 - H_{0,j}(s_0^i))} \right)^{-1}. \tag{11}$$

For simplicity of notation, we assume that the first m items are renegotiated in projects with change orders and these m tasks are also part of projects that are not renegotiated. Therefore, we can rewrite equation (11) for projects with no renegotiated items by separating items into two groups, $t = 1, ...m$ and $t = m + 1, ...T$,

$$\sum_{t=m+1}^{T} (b_{0,t}^i - c_{0,t}^i) q_{0,t}^e = \sum_{t=1}^{m} c_{0,t}^i q_{0,t}^e - \sum_{t=1}^{m} b_{0,t}^i q_{0,t}^e + \left(\sum_{j \neq i} \frac{h_{0,j}(s_0^i)}{(1 - H_{0,j}(s_0^i))} \right)^{-1}, \tag{12}$$

where the left hand side of equation (12) denotes tasks that are not renegotiated in other projects that can include renegotiated items. Moreover, equation (6) is equivalent to,

$$\begin{aligned} &\left[\sum_{t=1}^{m} (b_{1,t}^i - c_{1,t}^i) \tilde{q}_{1,t}^a + \sum_{t=m+1}^{T} (b_{1,t}^i - c_{1,t}^i) q_{1,t}^e - \sum_{t=1}^{m} \tau \left(\tilde{q}_{1,t}^a - q_{i,t}^e \right) \right] \\ &= \left(\frac{k_t q_t^a + (1 - k_t) q_t^e}{q_t^e} \right) \left(\sum_{j \neq i} \frac{h_{1,j}(s^i)}{(1 - H_{1,j}(s^i))} \right)^{-1}. \end{aligned} \tag{13}$$

By definition, because we use items that are not renegotiated in projects with renegotiation, we have that,

$$\sum_{t=m+1}^{T} (b_{0,t}^i - c_{0,t}^i) q_{0,t}^e = \sum_{t=m+1}^{T} (b_{1,t}^i - c_{1,t}^i) q_{1,t}^e, \tag{14}$$

suggesting that we can substitute equation (12) in the second term on the left hand side of equation (13). After some algebra, it is possible to evaluate the total cost distribution for the group of renegotiated items as follows,

$$\sum_{t=1}^{m} c_{1,t}^{i}\tilde{q}_{1,t}^{a} + \sum_{t=1}^{m} \tau\left(\tilde{q}_{1,t}^{a} - q_{i,t}^{e}\right) = \sum_{t=1}^{m} b_{1,t}^{i}\tilde{q}_{1,t}^{a} + \left[\left(\sum_{j\neq i}\frac{h_{0,j}(s_0^i)}{(1-H_{0,j}(s_0^i))}\right)^{-1} - \sum_{t=1}^{m} b_{0,t}^{i}q_{0,t}^{e} + \sum_{t=1}^{m} c_{0,t}^{i}q_{0,t}^{e}\right] - \left[\left(\frac{k_t q_{1,t}^{a} + (1-k_t)q_{1,t}^{e}}{q_{1,t}^{e}}\right)\left(\sum_{j\neq i}\frac{h_{1,j}(s_1^i)}{(1-H_{1,j}(s_1^i))}\right)^{-1}\right]. \tag{15}$$

To uncover the cost of renegotiated items, we first estimate the left hand side of equation (11) and then we use these estimates to obtain the left hand side of equation (15). Using the procedure introduced in Section 3.2, we can similarly obtain $\hat{h}_{0,j}$, $\hat{h}_{1,j}$, $\hat{H}_{0,j}$, $\hat{H}_{1,j}$, $\hat{k}_t$, and $\hat{q}_t^a$. In order to estimate $(c_{0,1},\ldots,c_{0,m})$, we first obtain $\hat{\mathbf{c}}_0$ from equation (11) and then obtain, $\hat{c}_{0,t}^{i} = b_{0,t}^{i}q_{0,t}^{e}\hat{\mathbf{c}}_0/s_0^i$ for $t = 1,\ldots,m$. Thus, each itemized cost in the subset $\mathcal{I}_A$ or $\mathcal{I}_B$ is constructed as a proportion of total project cost estimates. Those items experienced no renegotiations in these groups while they were renegotiated in contracts included in $\mathcal{I}_R$.

We present results for estimating the itemized cost distribution in Figure 3. The left panel offers results using the set of items in the subsample $\mathcal{I}_A$ and the panel on the right offers results using the set of items in the subsample $\mathcal{I}_B$. We showed in Table 7 that the itemized bid prices are much more similar than the itemized bid amounts, which is explained in part by observed differences in terms of quantities across items. Therefore, it is important to focus the analysis on comparing directly itemized unit costs instead of itemized costs.[20] Recall that we restrict attention to projects in which, at most, one item is renegotiated with positive quantity adjustment. Therefore, it is possible to solve for the cost of renegotiated items after we estimate equation (15) for each item $t \in \mathcal{I}_R$. Those cost estimates include production and adaptation costs. These pseudo costs are used to estimate the distribution

[20]This strategy allows us to control more successfully for unobserved production costs of certain tasks by considering the same items with and without renegotiation. By focusing on a similar set of tasks, if there are differences in pseudo-costs they have to be related to negotiation and not to project or item heterogeneity.

of the itemized unit cost for renegotiated items. Figure 3 shows that there are significant cost differences between a set of items when they are renegotiated and when they are not renegotiated.[21] Increased itemized unit costs might be a result of a number of factors, including workflow disruptions, additional work, dispute resolution, and the necessity of overtime pay associated with completing the task. Additionally, contractors carrying out projects in Vermont frequently have noted that when item quantities are increased in mid-project, this leads to increased costs for those items because suppliers charge for expedited or special shipping, and smaller shipments receive smaller quantity discounts. The figures also reveal that the empirical finding is robust, because the distributions of cost estimates for renegotiated items are similar and are not sensitive to employing either subsample $\mathcal{I}_A$ or $\mathcal{I}_B$.

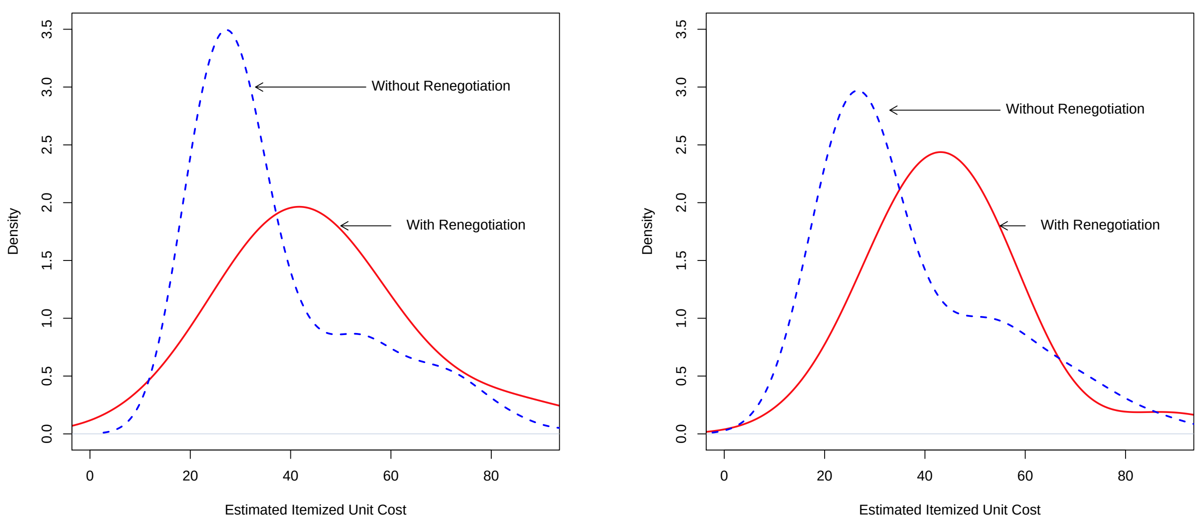

Figure 3: Itemized Unit Cost distribution for items with and without renegotiation using subsets $\mathcal{I}_A$ (left panel) and $\mathcal{I}_B$ (right panel). Unit costs are expressed in dollars.

It is important to note that we obtain different itemized cost estimates for projects with

[21] We calculated the Kolmogorov-Smirnov statistics for testing the hypotheses that the distribution of costs for $\mathcal{I}_R$ was the same as for $\mathcal{I}_A$ and $\mathcal{I}_B$. We reject both hypotheses at the one percent level.

Table 8: Markups for items with and without renegotiation

Subset	Percentile						
	20%	30%	40%	50%	60%	70%	80%
With renegotiation ($\mathcal{I}_R$)	9.268	10.209	11.792	15.905	17.766	27.893	33.918
Without renegotiation ($\mathcal{I}_A$)	2.524	3.698	4.782	6.545	9.333	10.934	15.580
With renegotiation ($\mathcal{I}_R$)	2.342	10.640	10.770	12.280	16.370	19.670	21.090
Without renegotiation ($\mathcal{I}_B$)	1.751	2.530	4.156	4.986	8.057	10.023	12.430
Non-renegotiated item in renegotiated projects	0.711	1.621	1.684	2.211	6.332	7.092	15.550
Non-renegotiated item in non-renegotiated projects	1.482	1.889	3.987	4.661	7.302	8.454	9.885

renegotiations depending on the alternative subsamples of items. Using a selected group of items that were renegotiated in some contracts and not in others during the period of analysis, we are able to offer a reliable comparison of latent costs. The cost estimates should not be affected by potential biases arising from latent item heterogeneity because we use item-specific cost estimates from the subsets $\mathcal{I}_A$ and $\mathcal{I}_B$ to estimate the itemized cost of items that were renegotiated in the period of analysis.

Table 8 shows bidders' strategic bidding behavior on the same items across cases when they are renegotiated and when they are not renegotiated. We infer that bidders bid less aggressively when there is a prospect of renegotiation and we examine this hypothesis by contrasting their bidding behavior when they bid on the same items with and without renegotiations. The median markup for renegotiated items is about 12-16%, which is much higher than that at the project level. On the other hand, the median markup for items that are not renegotiated is similar to that at the project level. Therefore, bidders seem to exhibit a different bidding behavior depending on whether the item is renegotiated. It is important to note that this result is not driven by the complexity or nature of these tasks, because we compare markups on items when they are renegotiated (items in the subset $\mathcal{I}_R$) to markups on the same items when they are not renegotiated (items in the subsets $\mathcal{I}_A$ or $\mathcal{I}_B$). Lastly, it is interesting to see significant differences between markups on items with and without positive quantity adjustments even though items that are renegotiated have higher unit costs than other identical items.

Table 8 naturally suggests that markups of items that were not renegotiated in renegotiated projects are expected to be lower than markups for these items in projects with no ex post renegotiation. However, the magnitude of this skewed bidding is unclear. We briefly address this question using the lower block of Table 8. We are able to estimate the markups for items that are not renegotiated in contracts that have renegotiated items.[22] We compare them with markups for the same set of items in contracts that have no renegotiated items. Our procedure for obtaining these estimates is as follows. First we subtract the cost estimate of the renegotiated item from the entire project cost estimate. Then, we estimate the pseudo costs for the other items in the same project by allocating the remainder of the project cost estimate among the non renegotiated items in proportion to their itemized bid amounts.

The results presented in the last rows of Table 8 imply that ex post renegotiation on an item could affect the entire project and bidders' bidding behaviors. Markups for the items that are not renegotiated in projects with renegotiation are much lower than the markups on items typically renegotiated, and they are slightly lower than the markups on the same items included in projects without renegotiation. (The sole exception is the comparison of markups at the upper tail). The pattern of strategically skewed bidding revealed here is consistent with that postulated by Athey and Levin (2001), adjusting for our different model of expectations based upon historical probabilities.

3.5 Counterfactuals

In this section, we conduct a counterfactual exercise to estimate the cost differences in con-

[22]After defining the set of non-renegotiated items in contracts with renegotiations, we found 155 items in a new subset $\mathcal{I}'_A$ which is analogous to $\mathcal{I}_A$ and 39 items in $\mathcal{I}'_B$ which is analogous to $\mathcal{I}_B$. The reason why we find different numbers of non renegotiated items in the two new subsets is because $\mathcal{S}_A$ consists of almost twice as many projects as $\mathcal{S}_B$, as shown in Table 4. The bottom part of Table 8 presents results based on the subset $\mathcal{I}'_B$, which consists of items from projects with no renegotiation or added/dropped items.

tracts when the probability of renegotiation decreases. The average historical probability of renegotiation for the six renegotiated items considered in the previous section is 18.48% during the sample period. In our structural model, we assume that the probability of renegotiation k_t for those items decreases by 5 percentage points. We assume that there is a positive linear relationship between itemized bid amounts and the probability of renegotiation, implying that bidders use the information on historical probabilities of renegotiation for those items when submitting their itemized bids. The assumption directly implies that an itemized bid increases proportionally with the increase in its historical probability. Using this assumption, we are able to adjust the observed itemized bids that would occur when the probability of renegotiations changes in the counterfactuals.

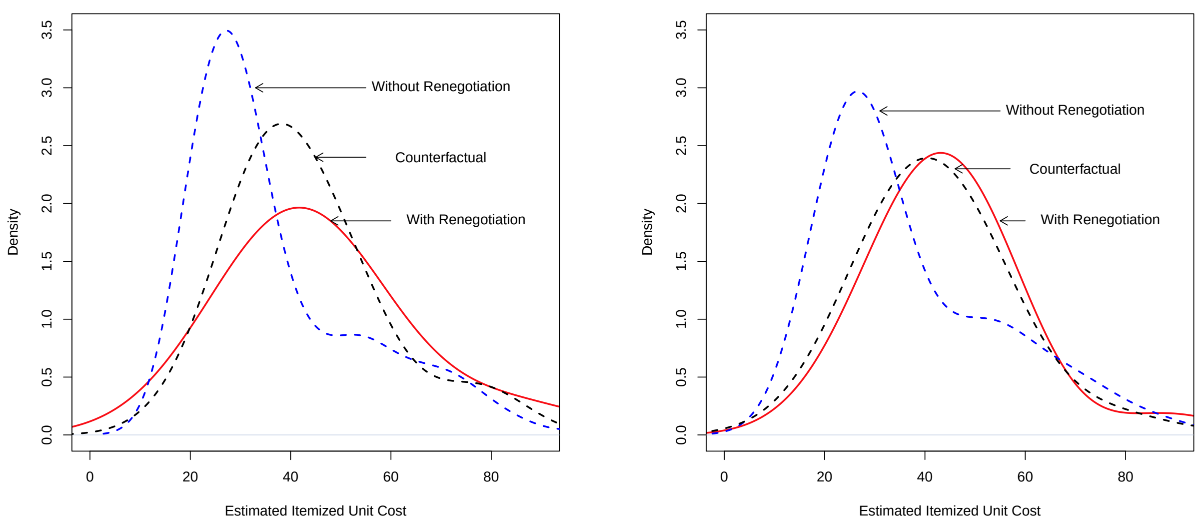

Figure 4: Counterfactual estimations for itemized costs using subsets $\mathcal{I}_A$ (left) and $\mathcal{I}_B$ (right). Unit costs are expressed in dollars.

Figure 4 reports the results of the exercise demonstrating how the cost distribution shifts when the probability of renegotiation changes marginally. The solid line indicates the estimated itemized cost using the empirical probability of renegotiation, $\hat{k}_t$. On the other hand, the dashed line presents the estimated itemized cost using the new probability. We incorpo-

Table 9: An analysis of estimated costs

	Renegotiation			Counterfactual		
	Median	Mean	Median Markup	Median	Mean	Median Markup
Itemized Costs using $\mathcal{I}_A$	\$581,400	\$680,900	15.905%	\$515,500	\$628,700	12.829%
Itemized Costs using $\mathcal{I}_B$	\$815,200	\$749,000	12.280%	\$748,300	\$696,700	11.814%

rate the adjusted itemized bids to estimate, from equation (15), the costs that would exist under this counterfactual scenario. As expected, we find that a slight decrease in probability of renegotiations causes the cost distribution to shift to the left.

Lastly, we report the estimated costs and markups in the counterfactual exercise (Table 9). We find that a 5% decrease in probability of renegotiation would lower itemized costs by 6.98% - 7.67% at the mean level, depending on the subsets $\mathcal{I}_A$ and $\mathcal{I}_B$. The change in costs due to the probability reduction ranges on average between \$52,200 - \$52,300. Moreover, we find that, as the probability of renegotiation decreases, contractors' markups are systematically decreased through their strategic reaction by 0.47 - 3.08%.

3.6 Endogenous change orders

A natural concern to the validity of our findings is that renegotiated projects and items might not be similar to non-renegotiated projects and items. Although the evidence seems to suggest that we satisfy a conditional independent assumption between change orders and bids, we might not account for selection on unobservables when we estimate a model at the project level. Thus, the estimation of equation (7) might lead to biased results, and thus, $\hat{h}$ and $\hat{H}$ might be biased too. We now examine the robustness of our findings to adopting an instrumental variable (IV) strategy for estimation of equation (7).

A valid instrument, in this case, would be an exogenous variable that is not associated with unobserved production costs, but does affect ex post changes to a project. Following Bajari, Houghton, and Tadelis (2014), we employ the identities of the state resident engineers

Table 10: Markups for projects with and without renegotiation

	Percentile						
Subset	20%	30%	40%	50%	60%	70%	80%
With Renegotiation ($\mathcal{S}_R$)	2.900	4.111	7.182	9.280	12.420	14.740	17.620
Without Renegotiation ($\mathcal{S}_A$)	2.286	2.994	3.754	5.440	8.606	10.820	15.000
Without Renegotiation ($\mathcal{S}_B$)	1.702	2.330	3.562	4.610	7.252	8.738	11.760
With renegotiation ($\mathcal{I}_R$)	0.337	7.392	10.316	10.975	15.568	23.676	38.618
Without renegotiation ($\mathcal{I}_A$)	2.389	3.291	4.018	6.416	9.709	12.520	15.686
With renegotiation ($\mathcal{I}_R$)	2.179	10.280	11.980	13.350	16.920	18.640	23.190
Without renegotiation ($\mathcal{I}_B$)	1.751	2.530	4.156	4.986	8.057	10.023	12.4300
Non-renegotiated item in renegotiated projects	0.557	1.360	1.572	2.057	6.259	7.086	9.969
Non-renegotiated item in non-renegotiated projects	1.482	1.889	3.987	4.661	7.302	8.454	9.885

as an instrumental variable. These engineers, employees of the state highway department, oversee the project's execution, and thus have considerable discretion over change orders. Statistical evidence of the relevance of the instrument is that the F-statistic on the resident engineer dummies in the first-stage regressions indicates statistical significance at the one percent level.[23] There is no evidence that within districts more experienced engineers are assigned to projects that are more susceptible to renegotiation. Furthermore, they are assigned to projects on the basis of administrative geographic organization, which in the case of Vermont is not related to the likelihood of change orders. Thus, there are strong reasons to believe that the instrument is valid.

The structural IV estimates are presented in Table 10. The IV results in the table follow quite closely the previous results from the models without the IV specification. That is, estimated markups are higher for projects with renegotiation ($\mathcal{S}_R$), and for items with renegotiation ($\mathcal{I}_R$). For project level comparisons of $\mathcal{S}_R$ with $\mathcal{S}_B$ and for the item-level comparison of $\mathcal{I}_R$ with $\mathcal{I}_B$, the distribution of markups is very close under the IV and non-IV specifications. For the item-level comparison of $\mathcal{I}_R$ with $\mathcal{I}_A$, the IV specification yields a markup distribution with a lower median and greater variance than the non-IV specification,

[23]First-stage regression results are available upon request.

but still significantly greater markups on renegotiated items versus non renegotiated items except in the 20^{th} percentile. In sum, the IV specifications provide evidence that is entirely consistent with the main findings presented earlier in the paper.[24]

4 Conclusion

This paper contributes to the auction and contracting literatures by providing empirical evidence on how ex post renegotiation in procurement contracting affects outlays on road construction contracts. We present detailed evidence that firms strategically alter their bids and markups when they anticipate contract renegotiations down the road. The analysis uses a nonparametric structural approach to estimate the distribution of latent costs after controlling for project and firm heterogeneity. Furthermore we assume that firms utilize the historical probability of renegotiating particular items rather than possessing perfect foresight of future renegotiations.

A distinguishing feature of this paper is that by examining itemized costs and markups, we are able to uncover the strategy by which the higher project-level margins are obtained. In particular, we estimate higher markups on items that have a history of frequent renegotiation. We find evidence of unbalanced or "skewed" itemized bidding that is based on a homogeneous subsample of projects. The increased profit margins obtained through strategic bidding are consistent with the view that firms often have information about the requirements of a project that is superior to that of the state engineer, and are able to exploit these advantages and their market position in order to add to their own profitability. In a competitive bidding environment with homogeneous firms, strategic bidding could not result in the higher profits that we estimate. In highway construction markets such as the one

[24] Note that since we are estimating equations separately for projects with and without renegotiation, we don't instrument for change orders in the specification pertaining to non renegotiated projects and therefore the results for S_B and I_B match the corresponding entries in Table 5 and Table 8 respectively.

in Vermont, there are good reasons to believe that there is substantial firm heterogeneity amplifying rent opportunities. Despite our efforts to control for unobserved and observed sources of heterogeneity, it is certainly possible that project-firm specific heterogeneity remains, representing sources of advantage to firms on individual tasks. For example, these advantages might originate in informational asymmetries across other dimensions or special financial and corporate linkages with key local input suppliers, limiting our ability to isolate the causes of increased profitability. Contracting agencies that wish to constrain bid skewing might employ a design that defines reimbursement amounts a priori, in a way that is independent of firm bidding as in typical asphalt or fuel price adjustment clauses.

Our work complements the important recent contribution by Bajari, Houghton, and Tadelis (2014) in that we estimate increases in project costs associated with contract renegotiations. Our counterfactual exercise indicates that as the probability of renegotiation decreases both the estimated itemized costs and markups change. Finally, we concur with their policy recommendation that states might consider "experimentation with more careful and costly design efforts." We would add that our results point to the possible benefits of more intensive use of "design-build" type contracting mechanisms, in which contractors participate directly at the planning stage. In that way their design expertise and specialized knowledge might be turned more to the buyer's advantage, and less as an instrument to raise the seller's profit.

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Appendix A: Tables

Table A.1 Regression variables

Dependent Variable	Descriptions and construction of the variable
Log of Bid	The weighted sum of unit prices and quantities on the original contract. The logarithm of bidding amount of each bidder on the original contract is used in the empirical analysis.
Log of Itemized Bid	The logarithm of itemized bids of each bidder.
Independent Variable	**Auction specific characteristics**
Price Adjustment	Ex post total price adjustment amount in the project (in millions of dollars). The price adjustment amount is the reimbursed amount according to the price adjustment clauses for fuel and asphalt.
Positive Quantity Adjustment	Ex post total positive quantity adjustment amount in the project (in millions of dollars).
Negative Quantity Adjustment	Ex post total negative quantity adjustment amount in the project (in millions of dollars).
Dropped Item Amount	The total value of dropped items from the original contract (in millions of dollars).
New Added Item Amount	The total value of new added items in the project (in millions of dollars).
Itemized Positive Quantity Adjustment	The dollar amount of ex post positive quantity adjustment at item level (in $10,000).
Itemized Negative Quantity Adjustment	The dollar amount of ex post negative quantity adjustment at item level (in $10,000).
Itemized Dropped Item Amount	The dollar amount of dropped item at item level (in $10,000).
Log of Engineer's Estimate	The logarithm of engineering cost estimates on the original contracts. In this analysis, we include the engineer's cost estimates at the auction level and itemized level depending on the dependent variable specifications
Log of Calendar Days	The number of calendar days that are required to complete the project. The logarithm of the number of calendar days is used in the empirical analysis.
Complexity	The number of unique items on the original contract (in 100 items).
Expected Number of Bidders	It is calculated using the past 12 month information for each bidder and plan-holder list. We construct the probability of submitting bids conditional on being a plan-holder. For an auction at time t, the expected number of bidders is the summation of the participation probabilities. Then, we multiply dummy variable to the expected number of bidders to identify an auction, in which the qualified plan-holders are more than 3 on the plan-holder list. The 3 qualified plan-holders are the threshold to release the information on plan-holders' identities.
Elevation	The height of a project work site (in 100 feet).
Asphalt Project	The dummy variable that takes the value one if a project is the asphalt paving project.
Bridge Project	The dummy variable that takes the value one if a project is the bridge project.
	Bidder specific characteristics

Top Firm	A firm is assigned as a top firm if its annual revenue value is greater than 15% of the total value of all firms' revenues each year during the sample period.
Debt to Asset Ratio	A firm's debt to asset ratio is the ratio of a firm's long term debt divided by its total asset every year.
Local Market Power	The total remaining value of a firm's ongoing projects in a county divided by the total remaining value of all firms' ongoing projects in that county at time t.
Log of Firm's Backlog	We assume that a project is completed in a uniform fashion over the length of the contract. A contract backlog is constructed by summing the remaining values of a firm's ongoing projects. However, if projects are completed, the backlog of the firm goes to zero. The logarithm of the amount of a bidder's current backlog is used in the empirical analysis.
Log of Rival's Minimum Backlog	The logarithm of the minimum of all rivals' backlog amounts in an auction.
Distance to the Project Locations	The distance between the firm's location and the location of work sites (in 100 miles). If a project needs to perform statewide, we consider its location as the center of the state. Moreover, if a project has multiple sub-projects, we take the average of the distances to each work site.
Rival's Minimum Distance	The minimum distance of all rivals' distances between work sites and their locations in an auction (in 100 miles).
	Variables on general economic conditions
Average Number of Building Permits	This variable measures the three month moving average of the monthly number of building permits issued in the state of Vermont. The data come from the US Bureau of Economic Analysis (in 10,000).
Unemployment Rate	The monthly unemployment rate in Vermont adjusted for seasonal fluctuations from the Bureau of Labor Statistics (BLS).
Monthly Dummies	There are in total 11 monthly dummies that control for the months of the year. The omitted month is December.

Table A.2: Regression results for a model of bids using homogeneous projects

	Project Bids		
Independent Variable	(1)	(2)	(3)
Price Adjustment			-0.086
			(0.155)
Dropped Item Amount			-0.112
			(0.256)
New Added Item Amount			-0.039
			(0.248)
Change Order Indicator	0.061**	0.036	
	(0.028)	(0.046)	
Positive Quantity Indicator			0.040
			(0.044)
Log of Engineer's Estimate	0.858***	0.857***	0.864***
	(0.017)	(0.041)	(0.042)
Log of Calendar Days	0.078***	0.002	0.001
	(0.024)	(0.046)	(0.049)
Complexity	0.105	0.361**	0.336**
	(0.064)	(0.154)	(0.155)
Number of Bidders	-0.028***	-0.018	-0.008
	(0.006)	(0.049)	(0.053)
Distance to the Project Location	-0.009	-0.028	-0.032
	(0.033)	(0.067)	(0.068)
Rival's Minimum Distance to the Project Location	0.043	-0.051	-0.050
	(0.038)	(0.078)	(0.080)
Top Firm	0.026	0.023	0.021
	(0.036)	(0.062)	(0.064)
Firm Fixed Effects (55)	Yes	Yes	Yes
Observations	846	141	141

*** Denotes statistical significance at the 1% level, ** denotes significance at the 5% and * denotes significance at the 10% level. Clustered standard errors are in parentheses.

Appendix B: Derivation of the equilibrium bidding function

We assume that there are 4 bidders such as i, j, k and l to show how we derived equation (4). Equation (2) can be written as,

$$\pi^i(\mathbf{b}^i,\mathbf{c}^i,\mathbf{k}) = \left[\left(\mathbf{b}^i-\mathbf{c}^i\right)\cdot(\mathbf{k}\cdot\mathbf{q}^a+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)-\mathbf{k}\tau\cdot(\mathbf{q}^a-\mathbf{q}^e)\right]\left[(1-H_j(s^i))(1-H_k(s^i))(1-H_l(s^i))\right].$$

Note that $s^i = \mathbf{b}^i \cdot \mathbf{q}^e$. After we take a derivative of a bidder's expected payoff function with respect to bidder i's unit price, we get

$$\begin{aligned}\frac{\partial \pi^i(\mathbf{b}^i,\mathbf{c}^i,\mathbf{k})}{\partial b^i_t} &= (k_t q^a_t + (1-k_t)q^e_t)\times\left[(1-H_j(s^i))\times(1-H_k(s^i))\times(1-H_l(s^i))\right]+\left[\left(\mathbf{b}^i-\mathbf{c}^i\right)\cdot(\mathbf{k}\cdot\mathbf{q}^a\right.\\ &\left.+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)-\mathbf{k}\tau\cdot(\mathbf{q}^a-\mathbf{q}^e)\right]\times\left[q^e_t\left[-h_j(s^i)(1-H_k(s^i))(1-H_l(s^i))-h_k(s^i)(1-H_j(s^i))\right.\right.\\ &\left.\left.(1-H_l(s^i))-h_l(s^i)(1-H_j(s^i))(1-H_k(s^i))\right]\right]=0. \qquad (16)\end{aligned}$$

This equation can be written as,

$$\begin{aligned}\frac{\partial \pi^i(\mathbf{b}^i,\mathbf{c}^i,\mathbf{k})}{\partial b^i_t} &= (k_t q^a_t + (1-k_t)q^e_t)\times\left[\prod_{j\neq i}(1-H_j(s^i)\right]-\left[\left(\mathbf{b}^i-\mathbf{c}^i\right)\cdot(\mathbf{k}\cdot\mathbf{q}^a+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)-\mathbf{k}\tau\cdot(\mathbf{q}^a-\mathbf{q}^e)\right]\\ &\times\left[q^e_t\sum_{k\neq i}h_k(s^i)\prod_{j\neq i,k}(1-H_j(s^i))\right]=0\end{aligned}$$

Now we divide equation (16) above by $\left[(1-H_j(s^i))\times(1-H_k(s^i))\times(1-H_l(s^i))\right]$ to obtain,

$$(k_t q^a_t + (1-k_t)q^e_t)-\left[\left(\mathbf{b}^i-\mathbf{c}^i\right)\cdot(\mathbf{k}\cdot\mathbf{q}^a+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)-\mathbf{k}\tau\cdot(\mathbf{q}^a-\mathbf{q}^e)\right]\times\left[q^e_t\sum_{j\neq i}\frac{h_j(s^i)}{(1-H_j(s^i))}\right]=0$$

Simplifying we get equation (4):

$$(\mathbf{b}^i-\mathbf{c}^i)\cdot(\mathbf{k}\cdot\mathbf{q}^a+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)-\mathbf{k}\tau\cdot(\mathbf{q}^a-\mathbf{q}^e)=\left(\frac{k_t q^a_t+(1-k_t)q^e_t}{q^e_t}\right)\times\left(\sum_{j\neq i}\frac{h_j(s^i)}{(1-H_j(s^i))}\right)^{-1}.$$