Strategic Bidding and Contract Renegotiation*

Hojin Jung†, Georgia Kosmopoulou‡, Carlos Lamarche§ and Richard Sicotte¶

Abstract

When firms anticipate that procurement contracts are renegotiated after they are awarded, they incorporate these expectations into their ex ante bidding behavior, often significantly raising the costs of public procurement. We estimate the incidence and magnitude of strategic bidding using recent data on the bidding and renegotiation of road construction projects in Vermont, focusing on contracts in which specific item amounts are increased after a project is awarded. We develop a structural model that allows firms to predict such quantity adjustments based on their historical probabilities and the necessity of renegotiation due to incomplete engineers' project plans. Our empirical analysis shows that the magnitude of estimated markups is systematically higher for projects with positive quantity adjustments than those without such renegotiations. At the itemized level, these effects intensify with markups making up 16-18% of the bid. In the same projects, bidders lower their markups on items that are not renegotiated, creating a pattern of strategically skewed bids.

JEL Classification: D44, D82, H57, L14, L22, L74.
Keywords: Mechanism design, government procurement, contracting.

*The authors would like to thank Javier Donna and conference participants at the 2013 International Industrial Organization Conference for comments related to this work. We are indebted to staff at the Vermont Agency of Transportation (VTrans) for providing useful information. This research has been supported by VTrans Grant No. SPR722. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

†Illinois State University, Normal, IL 61790; e-mail: hjjung1@ilstu.edu

‡Corresponding author: National Science Foundation, Arlington, VA 22230 and University of Oklahoma, Norman, OK, 73019; e-mail: georgiak@ou.edu

§University of Kentucky, Lexington, KY 40506; e-mail: clamarche@uky.edu

¶University of Vermont, Burlington, VT 05405; e-mail: richard.sicotte@uvm.edu

1 Introduction

Contractual incompleteness is a natural, perhaps unavoidable attribute of procurement for complex projects. A consequence is that there are often significant differences between the original contract specifications and the actual labor and materials required when the project is finally brought to completion. Such discrepancies lead to extensive, costly ex post renegotiations between procuring agencies and contractors. US government 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. However, quantity adjustments are common, and firms that anticipate quantity renegotiation often modify their bidding strategies accordingly. In Athey and Levin (2001), for example, contractors are able to increase their profits by submitting high (low) unit prices on items in anticipation of unit additions (deductions) after they begin work on a project. This study examines how the prospect of ex post renegotiation in road construction affects outlays by the Vermont Agency of Transportation, placing the focus on the impact of positive quantity adjustments.

Existing work (see 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 frequencies of renegotiation at the item level and the need for such adjustments. First, we employ reduced form estimation in order to study the relationship between bidding behavior and the different forms of contract renegotiation, while controlling for a variety of factors, including competition, local market power and firms' debt to asset ratios. We then restrict our focus to a set of contracts that fit the Independent Private Value (IPV) model and consider one of the most costly forms of renegotiation, namely, positive quantity adjustments. Positive quantity adjustments, as opposed to price adjustments or new item additions, are reimbursed at a price that is determined by the contractor at the bidding stage. As such, there are incentives for bid manipulation that are absent in price adjustments where market based indexes are used.

Bajari, Houghton, and Tadelis (2014) show that renegotiations in standard low price procurement auctions may generate significant additional transaction costs. In their study of the California highway construction industry, they estimate these costs to be $2.20 for every dollar worth of positive quantity adjustments. Furthermore, renegotiations often distort contractors' ex ante incentives. Bidders may consider renegotiations as an opportunity to seek additional rents. Iossa, Spagnolo, and Vellez (2007) argue that renegotiations can have negative impact on ex ante efficiency because a bidder has weak incentives to reduce cost or improve quality. The Federal Acquisition Regulation (FAR) guidelines demonstrate a clear preference for simple competitive price-based auctions. However, Bajari and Tadelis (2006) and Chong, Staropoli, and Yvrande-Billon (2009), argue that renegotiations may improve efficiency in procurement when projects are complex or when less potential competition is expected. Bajari, McMillan, and Tadelis (2009) assert that procurement officials should be allowed more flexibility in awarding contracts based on the characteristics of projects and bidders. One such example is that many projects require large amounts of materials, such as asphalt, that are subject to substantial price volatility. Kosmopoulou and Zhou (2014) and Kosmopoulou, Lamarche, and Zhou (2014) find that the introduction of price adjustment clauses in procurement contracting has benefited significantly the Oklahoma Department of Transportation as bids are more competitive and the failure rate of firms is lower, creating net savings to the state program. When a framework for renegotiations exists and reimbursements are independent of a contractor's bid level the effects of renegotiation on the budget can be positive. Reimbursement for quantity renegotiation is not independent of the initial bid and as such creates the potential for bidders to increase their markups through relative bid distortions.

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 coordination and dispute resolution 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 IPV 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 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 differing probabilities of renegotiation provides evidence on how firms' anticipation of change orders affects their bidding behavior. Our approach also permits us to conduct counterfactual experiments to measure how changes in the probability of renegotiation shifts our estimated distribution of firms' costs and markups.

Our sample consists of all highway construction projects let via the standard low price auction procedure in the state of Vermont over a five-year period. We first estimate the model 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 suggest that while bidders increase their markups on items that have a high likelihood of renegotiation by 10-11% 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.

The rest of the paper proceeds as follows. Section 2 provides an overview of the data. In Section 3, we present the model and our identification strategy and discuss structural empirical analysis. Section 4 offers concluding remarks.

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 857 bids (more than 50,000 itemized bids) on 312 individual projects. We classify auctions by project type: asphalt projects, bridge projects and miscellaneous projects.[1] The weekly sealed-bid auctions award the contract to the lowest bidder. 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.[2] 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 level on the list.

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

[2]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.

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 (American Institute of Architects, 2007) 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.[3] They include ex post payments made by positive quantity, 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 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 9.20% above the engineering cost estimate and win with bids that are 2.30% below the

[3]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: Descriptive Statistics

Variable	Mean	Standard Deviation	Min	Max	Number of Observations
Itemized Relative Bid (before Change Orders)	1.162	0.673	0.000	4.000	50,465
Itemized Bidding Amount	$0.028	$0.124	$0.000	$5.077	50,465
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	$1.723	$2.282	$0.025	$29.505	857
Relative Bid (before Change Orders: (Bid / Engineering Cost Estimate)	1.092	0.277	0.500	2.339	857
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.

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 in the contract is used as a proxy for project complexity. The average number

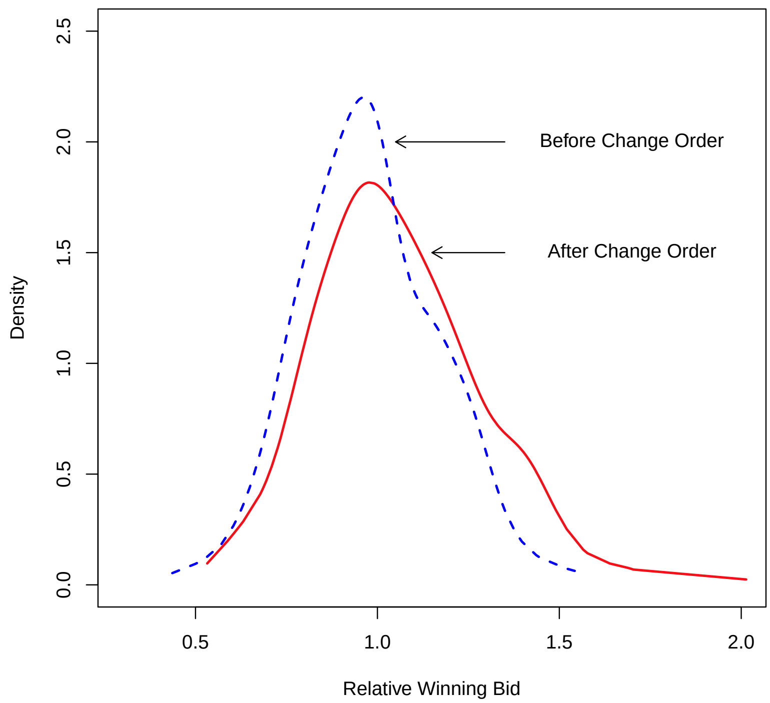

Figure 1: Kernel Density Plot of Relative Winning Bids

of items per contract is 60.

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 adjustments are based on a market index that is independent of firms' reported bids.[4] They are triggered by fluctuations in the price of oil caused by economic uncertainty. In contrast,

[4]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.

quantity adjustments lead to direct bid skewness that is not observed in the presence of other types of change orders, and merit more attention. Those adjustments are often due to errors in the engineers' plans that might be recognized by experienced contractors. Our goal is to investigate whether there are indeed distinct effects that are more prominent when quantity adjustments become commonplace.

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:

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

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 specific 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 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 $\mathbf{X}$ 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.[5] We also use the "project type" dummy to control for bidding behavior across different types of 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.[6] 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.[7] 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 competitively. Kosmopoulou, Lamarche, and Zhou (2014) 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.[8] To control for the possibility of systematic

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

[6]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.

[7]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.

[8]The highway construction market is highly concentrated in 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

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 affect the 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.

Notice that we also use different sample sizes in this reduced form analysis. While we estimate the model using the full set of data, we also estimate the model with the subsample of projects used in the structural estimation of section 3. In Table 2, we estimate the models using ordinary least squares (OLS) with clustered standard errors (column (1)) and then fixed effects to account for firms' different efficiency levels (columns (2)-(6)). The introduction of firm fixed effects controls for any additional idiosyncratic characteristic of individual bidders that may drive bidding strategies. We report cluster-robust standard errors where clustering is at the auction level.

Lastly, this analysis also includes the itemized bid estimation with the unit of observation being an itemized bid during the period of analysis. For this analysis, we use similar control variables as in the project level specifications but we also include item fixed effects to capture different characteristics of tasks.[9] Furthermore, we classify all items into three groups: items with ex post quantity overruns, items with ex post quantity under-runs, and items with no quantity changes ex post. There are 712 different items used during the sample period. Of

(2014).

[9]In particular, we measure positive quantity adjustment, negative quantity adjustment and dropped item amounts at the itemized level for the itemized bid analysis.

Table 2: Regression Results for a Model of Bids

	Project Bids					Itemized Bids
	Full Sample			Subsample		Full Sample
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)
Positive Quantity Adjustment	0.096	0.121				0.011**
	(0.079)	(0.090)				(0.005)
Negative Quantity Adjustment	-0.082	-0.153				-0.003***
	(0.100)	(0.098)				(0.000)
Price Adjustment	-0.198*	-0.276**			-0.088	-0.203**
	(0.107)	(0.108)			(0.155)	(0.080)
Dropped Item Amount	-0.199	-0.244*			-0.111	-0.007**
	(0.129)	(0.130)			(0.253)	(0.004)
New Added Item Amount	-0.091	-0.134			-0.053	0.048***
	(0.116)	(0.115)			(0.246)	(0.017)
Change Order Indicator			0.067**	0.036		
			(0.027)	(0.046)		
Positive Quantity Indicator					0.031	
					(0.042)	
Log of Engineer's Estimate	0.916***	0.888***	0.869***	0.857***	0.864***	0.898***
	(0.017)	(0.018)	(0.017)	(0.041)	(0.042)	(0.005)
Log of Calendar Days	0.065***	0.086***	0.078***	0.002	0.004	0.036**
	(0.029)	(0.027)	(0.023)	(0.046)	(0.049)	(0.016)
Complexity	0.053	0.022	0.076	0.361**	0.348**	-0.005
	(0.073)	(0.071)	(0.069)	(0.154)	(0.157)	(0.033)
Expected Number of Bidders	-0.016***	-0.020***	-0.028***	-0.018	-0.013	-0.024***
	(0.006)	(0.006)	(0.006)	(0.049)	(0.053)	(0.004)
Distance to the Project Location	-0.002	-0.020	-0.015	-0.028	-0.035	0.017
	(0.022)	(0.031)	(0.033)	(0.067)	(0.069)	(0.021)
Rival's Minimum Distance to	-0.019	0.032	0.048	-0.051	-0.055	-0.015
the Project Location	(0.030)	(0.034)	(0.037)	(0.078)	(0.081)	(0.030)
Top Firm	-0.030	-0.017	0.028	0.023	0.018	-0.085***
	(0.028)	(0.037)	(0.036)	(0.062)	(0.064)	(0.032)
Local Market Power	-0.115***	-0.094***				-0.054**
	(0.028)	(0.031)				(0.025)
Debt to Asset Ratio	-0.076	-0.101				0.137*
	(0.047)	(0.091)				(0.081)
Debt to Asset Ratio* Top Firm	-0.278	-1.466				-1.302
	(0.335)	(1.121)				(0.914)
Elevation	0.002	0.002				0.004*
	(0.003)	(0.003)				(0.002)
Log of Firm's Backlog	0.002	0.002				0.003**
	(0.001)	(0.002)				(0.001)
Log of Rival's Minimum Backlog	-0.001	-0.003				-0.002*
	(0.001)	(0.002)				(0.001)
Average Number of Building	-0.003	-0.003				-0.009
Permits	(0.009)	(0.009)				(0.005)
Unemployment Rate	-0.037***	-0.028***				-0.013*
	(0.011)	(0.010)				(0.007)
Asphalt Project	0.054	0.007				0.014
	(0.051)	(0.051)				(0.031)
Bridge Project	0.088	-0.011				-0.034
	(0.054)	(0.052)				(0.031)
Time Dummy	Yes	Yes	No	No	No	Yes
Firm Fixed Effects (55)	No	Yes	Yes	Yes	Yes	Yes
Item Fixed Effects (709)	No	No	No	No	No	Yes
Observations	857	857	857	141	141	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.

those, 498 items never appear on a change order.

Results from this estimation are displayed in Table 2. The coefficient on the ex post positive quantity adjustment amount is positive and statistically significant at the itemized level, indicating that when bidders anticipate larger amounts of positive quantity adjustment, they bid less aggressively. Meanwhile, the variable related to the ex post negative quantity adjustment is negative and statistically significant at the itemized level. The direction of these adjustments allows us to conclude that bidders are likely to manipulate their bids in anticipation of ex post quantity adjustments to increase their ex post reimbursements. By doing so, bidders increase the probability to win the project, and later recover their forgone profits. This is consistent with theory (see Athey and Levin (2001)). The result that the quantity adjustment coefficients are statistically significant at the itemized level, and are not statistically significant at the project level, lends support to the hypothesis that firms engage in bid skewing that leaves overall bid levels more or less constant.

The coefficient on the ex post price adjustment amount is negative and statistically significant. Thus, considering the variable on price adjustment, 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. As a result, they increase their bids to reduce risk exposure in long-term contracts. In contrast with some previous work, we include price adjustment clauses in our reduced-form model presented in equation (1). If these are not controlled for, their effects on bidding behavior may bias the estimated effects of other factors, including the anticipation of quantity adjustments.

The anticipation of addition of new items in the field as a sign of uncertainty makes bidders more likely to bid less aggressively at the itemized level, but the variable is not statistically significant at the project level. Under perfect foresight and without consideration of the consequence of submitting unbalanced bids, bidders would be expected to bid zero on items that will be eventually dropped from a project. We observe lower bids on these items in our sample. 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. Bidders are more likely to incorporate a premium for ex 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. In the firm fixed effect specifications at the itemized level, the debt to asset ratio is statistically significant and positive, implying that financially constrained firms bid less aggressively at the item level. Likewise, the elevation of work site is statistically significant only in the itemized bid specification. The variable on backlog is positive and statistically significant, showing that capacity constrained firms bid less aggressively. The magnitude of this estimate is small in this case, perhaps showing that the contractual commitment of firms in Vermont relative to their overall workload could be small.

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, bidder characteristics and measures of economic fluctuation. An alternative structural approach is currently used in the empirical auction literature by assuming that the observed bids are the Bayesian Nash Equilibria of the theoretical model. This structural approach 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.

Lastly, the analysis in the third column of Table 2 shows that projects that have ex post renegotiations have a significantly different bidding pattern than projects that do not have ex post renegotiations. This naturally raises a concern about the possibility of a type of selection bias in the structural analysis. The model presented in the third column is estimated with a restricted set of covariates that includes auction specific characteristics and bidder observable variables, as in Bajari, Houghton, and Tadelis (2014). The first set of variables is expected to be associated with whether a project is likely to have ex post renegotiations. For instance, it is anticipated that a larger and more complex project has a higher likelihood of renegotiation than a small and less complex project. We also include observable bidder variables such as firm's distance to project location and a variable indicating whether a bidder is a top firm. In the analysis that follows, we overcome selection issues by using subsets of projects with and without renegotiations. We refer the reader to Subsection 3.3 where we explain in detail how we obtain subsets of homogeneous projects. In contrast to our results using the full sample, when we estimate the model using only the subsample of homogeneous projects the indicator variable of a change order is no longer statistically significant. This result is suggesting that

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.

a change order is randomly assigned conditional on observable covariates.

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.[10] For instance, the task associated with Superpave Bituminous Concrete Pavement, or item 490.30, has roughly 1/3 chance of being

[10]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).

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, an experienced 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 simple 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

We derive equilibrium bidding functions assuming that bidders have prior beliefs regarding the likelihood of renegotiations and then, we estimate the latent cost distributions using observed bids. 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 $H_j(s^i) \equiv \mathrm{pr}(\mathbf{b}^i \cdot \mathbf{q}^e > \mathbf{b}^j \cdot \mathbf{q}^e)$. 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 rational expectations 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.

Firm i's expected profit is $\mathbf{b}_i - \mathbf{c}_i$ if it wins the project and zero otherwise. We define bidder i's expected profit function as follows:

$$\begin{aligned}\pi^i(\mathbf{b}^i,\mathbf{c}^i,\mathbf{k}) &= \left[\mathbf{b}^i\cdot(\mathbf{k}\cdot\mathbf{q}^a+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)-\mathbf{c}^i\cdot(\mathbf{k}\cdot\mathbf{q}^a_t+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)\right]\times\left[\mathrm{pr}\left(\mathbf{b}^i\cdot\mathbf{q}^e<\mathbf{b}^j\cdot\mathbf{q}^e\right)\right]\\ &= \left[\mathbf{b}^i\cdot(\mathbf{k}\cdot\mathbf{q}^a+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)-\mathbf{c}^i\cdot(\mathbf{k}\cdot\mathbf{q}^a_t+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)\right]\times\left[\prod_{j\neq i}(1-H_j(s^i))\right], \quad (2)\end{aligned}$$

where the vector $\mathbb{1}$ is a T-dimensional vector of ones. 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:

$$\begin{aligned}\frac{\partial\pi^i(\mathbf{b}^i,\mathbf{c}^i,\mathbf{k})}{\partial b^i_t} &= (\mathbf{k}\cdot\mathbf{q}^a+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)\left[\prod_{j\neq i}(1-H_j(s^i))\right]-\left[\mathbf{b}^i\cdot(\mathbf{k}\cdot\mathbf{q}^a+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)\right.\\ &\quad \left.-\mathbf{c}^i\cdot(\mathbf{k}\cdot\mathbf{q}^a+(\mathbb{1}-\mathbf{k})\cdot\mathbf{q}^e)\right]\times\left[q^e_t\sum_{k\neq i}h_k(s^i)\prod_{j\neq i,k}(1-H_j(s^i))\right]=0. \quad (3)\end{aligned}$$

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

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

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:

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

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

$$(\mathbf{b}^i-\mathbf{c}^i)\cdot\tilde{\mathbf{q}}^a=\left(\frac{k_tq^a_t+(1-k_t)q^e_t}{q^e_t}\right)\left(\sum_{j\neq i}\frac{h_j(s^i)}{(1-H_j(s^i))}\right)^{-1} \quad (6)$$

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. 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. The vector $\mathbf{z}$ also includes contractor fixed effects to control for unobserved bidder heterogeneity in the first step of the structural estimation.[11,12]

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.[13] 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 these 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 $\widehat{\varepsilon}_{rj}^{(m_r)}$, $\kappa = 2.9878 \times 1.06$, and L_{rj} is the number of auctions in which bidder j participated.

[11] 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 6, 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).

[12] The results from estimating equation (7) were similar to the results presented in Table 2's column (4). 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.

[13] 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 6).

Lastly, after estimating the density function, we are able to uncover the cost distributions by solving the following two equations in terms of the unknowns $\mathbf{c}_0^i$ and $\mathbf{c}_1^i$,

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

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

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. We denote the solution of equations (9) and (10) by $\hat{\mathbf{c}} = (\hat{\mathbf{c}}_0', \hat{\mathbf{c}}_1')'$ which represent pseudo-values of the costs of projects without and with ex post renegotiations, respectively.

3.3 Data

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 more accurately their costs for asphalt projects and less so for bridge projects that are typically studied in a common value setting (see also Hong and Shum (2002) and De Silva, Dunne, Kankanamge, and Kosmopoulou (2008)).

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 to define three subsets of projects that corresponds to these equations. We denote the

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.

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 defined as $\mathcal{S}_A = \{(m_{\mathcal{A}}, t) : q_t^a = q_t^e,\ \forall (m_{\mathcal{A}}, t) \in \mathcal{A}_A \times \mathcal{T}\}$, 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. 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

Table 5: Comparison of Summary Statistics for Pay Items

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

Standard errors are in parentheses.

in the previous sections which follows closely Guerre, Perrigne, and Vuong (2000), Haile, Hong, and Shum (2006), and Bajari, Houghton, and Tadelis (2014).

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 5, and focus on their cost estimates or their markups at the itemized level.[14] 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 $\mathcal{I}_A$ and $\mathcal{I}_B$ denote subsets that include these items. As an illustrative example, while item

[14]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.

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.

3.4 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 red line indicates the project cost estimates for renegotiated projects while the dotted blue 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 or adaptation costs evident at the project level.

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

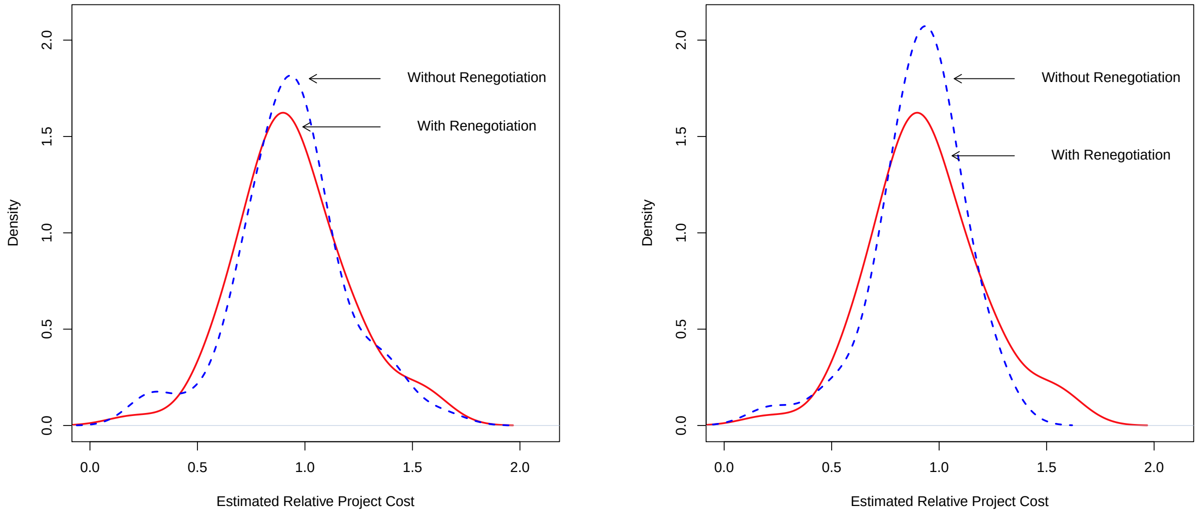

Figure 2: Relative cost in projects with and without renegotiation using subsets $\mathcal{S}_A$ (left panel) and $\mathcal{S}_B$ (right panel)

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) report that the median markup above the cost estimate is 8.5% for all bids and 18% for winning bids when considering adaptation costs. However, without accounting for contract renegotiations, the estimated markup drops to 3.7% for all bids and 12.52% for winning bids. The comparison across results of the previous literature affirms that renegotiation is critical for the correct determination of markups.

In Table 6, we summarize our estimates of bidders' markups over estimated costs for projects with and without positive quantity renegotiations after controlling for unobserved heterogeneity.[15] 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

[15] Krasnokutskaya (2011) points out that the estimated average markups could be considerably higher when failing to control for unobserved heterogeneity.

Table 6: Markups for projects with and without renegotiation

	Percentile						
Group	20%	30%	40%	50%	60%	70%	80%
With Renegotiation ($\mathcal{S}_R$)	2.532	4.072	7.476	8.695	12.300	15.090	17.400
Without Renegotiation ($\mathcal{S}_A$)	2.594	3.362	4.070	5.750	7.956	9.174	13.440
Without Renegotiation ($\mathcal{S}_B$)	1.702	2.310	3.562	4.610	7.072	9.194	11.760

estimated median markups are similar to those reported in Bajari, Houghton, and Tadelis (2014). The estimated median markups are 8.70% 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 slightly 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 6 suggests a difference of 3-4% at the median level between markups in contracts with and without renegotiation.

3.5 Estimation of itemized costs

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 5 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, 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,

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

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,

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

To uncover the cost of renegotiated items, $(c_{1,1},\ldots,c_{1,m})$, 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 5 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. 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 $c_{1,t}^{i}$ after we estimate equation (15) for each item $t\in\mathcal{I}_R$. These pseudo costs are used to estimate the distribution 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. 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 $\mathcal{I}_B$.

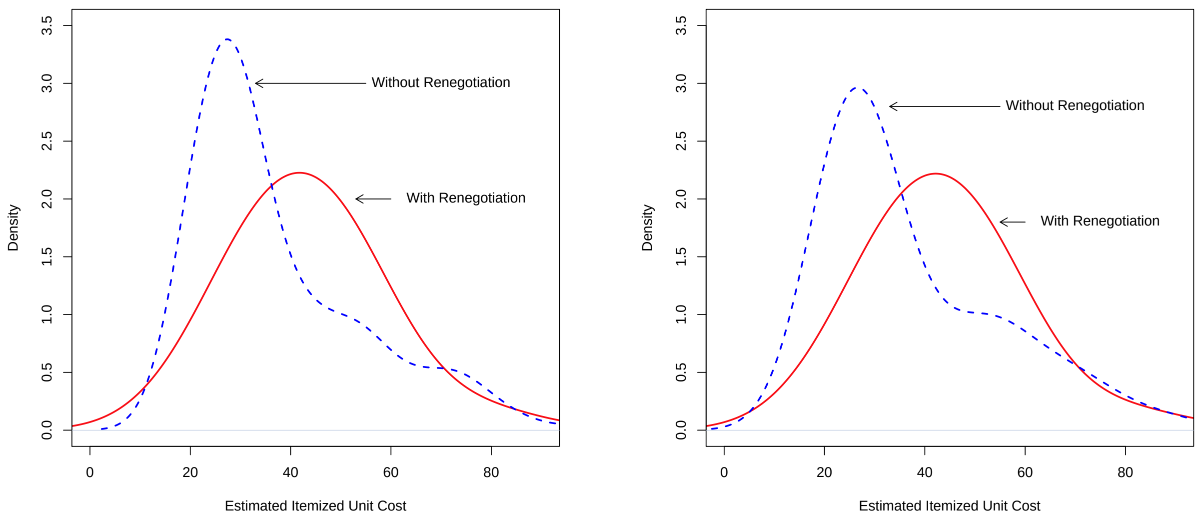

Figure 3: Itemized Unit Cost distribution for items with and without renegotiation using subsets $\mathcal{I}_A$ (left panel) and $\mathcal{I}_B$ (right panel). Unit costs are expressed in dollars.

It is important to note that we obtain different itemized cost estimates for projects with 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 7: Markups for items with and without renegotiation

	Percentile						
Group	20%	30%	40%	50%	60%	70%	80%
With renegotiation ($\mathcal{I}_R$)	7.319	11.510	13.720	17.900	21.950	22.760	31.470
Without renegotiation ($\mathcal{I}_A$)	2.763	3.603	4.188	7.000	8.195	9.232	13.540
With renegotiation ($\mathcal{I}_R$)	4.138	10.760	11.920	16.300	17.600	19.900	28.440
Without renegotiation ($\mathcal{I}_B$)	1.751	2.530	4.156	4.986	7.302	10.023	12.430
Non-renegotiated item in renegotiated projects	1.309	1.492	3.828	3.906	6.167	7.073	14.144
Non-renegotiated item in non-renegotiated projects	1.482	2.149	3.987	4.661	6.906	9.017	9.885

Table 7 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 16-18% 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 7 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 7. We are able to estimate the markups for items that are not renegotiated in contracts that have renegotiated items.[16] 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 7 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, shown in first rows of Table 7, 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.

3.6 Testing the cost distribution invariance

This section reports non-parametric tests for equality of cost distributions. We employ the standard Kolmogorov-Smirnov test (KS test in Table 8). This statistic is commonly used in the literature to test for differences between two distributions, and we use it to evaluate the null hypothesis of no difference in the cost distributions of projects with and without renegotiations. Based on the results offered in Table 8, we fail to reject the null of equality of project cost distributions. At the itemized level, the results indicate that the difference in itemized cost distributions between items with and without renegotiations is statistically

[16]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 7 presents results based on the subset $\mathcal{I}'_B$, which consists of items from projects with no renegotiation or added/dropped items.

Table 8: Tests for invariance of cost distributions to renegotiations

		With Renegotiation			Without Renegotiation			Tests
Subset	Estimated Costs	Median	Mean	SD	Median	Mean	SD	(KS)
$\mathcal{S}_A$	Relative Project Cost	0.907	0.942	0.256	0.927	0.936	0.259	0.955
$\mathcal{I}_A$	Itemized Unit Cost ($)	44.964	54.188	44.596	21.668	35.119	34.336	0.013
$\mathcal{S}_B$	Relative Project Cost	0.907	0.942	0.256	0.936	0.906	0.204	0.558
$\mathcal{I}_B$	Itemized Unit Cost ($)	45.038	55.174	44.581	19.081	34.702	34.815	0.002

The last column of the table provides p-values corresponding to the Kolmogorov-Smirnov (KS) test.

significant at the 1% level. That evidence is consistent with Figure 3 which shows that the location of cost distributions for those items are significantly different. Our finding lends support to the hypothesis that renegotiation is associated with higher costs at the item level. The items whose costs significantly increase due to renegotiation represent a small proportion of the total project costs, explaining in part the seemingly conflicting finding at the project and item levels.

3.7 Counterfactuals

In this section, we conduct a counterfactual exercise to estimate the cost differences in contracts 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 reports the results of the exercise demonstrating how the cost distribution shifts

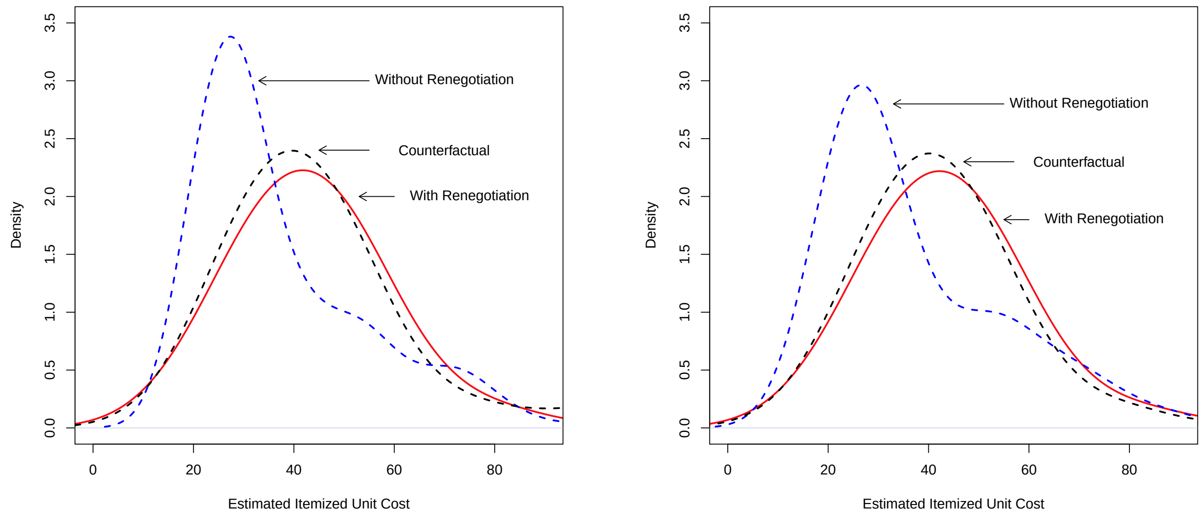

Figure 4: Counterfactual estimations for itemized costs using subsets $\mathcal{I}_A$ (left) and $\mathcal{I}_B$ (right). Unit costs are expressed in dollars.

when the probability of renegotiation changes marginally. The solid red 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 incorporate 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 7.06% - 7.24% 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 \$51,900 - \$52,000. Moreover, we find that, as the probability of renegotiation decreases, contractors' markups are systematically decreased through their strategic reaction by 2.96 - 3.89%.

Table 9: An Analysis of Estimated Costs

	Renegotiation			Counterfactual		
	Median	Mean	Median Markup	Median	Mean	Median Markup
Itemized Costs using $\mathcal{I}_A$	$797,500	$716,400	17.900%	$727,600	$664,500	14.938%
Itemized Costs using $\mathcal{I}_B$	$821,500	$736,500	16.300%	$751,700	$684,500	12.403%

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 the 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. Bid skewness could be limited by 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 changes both the estimated itemized costs and markups. 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.

References

American Institute of Architects, 2007. General Conditions of the Contract for Construction.

Athey, S. and Levin, J., 2001. Information and Competition in US Forest Service Timber Auctions, *Journal of Political Economy*, 109 (2), 375–417.

Bajari, P., 2001. Comparing Competition and Collusion: a Numerical Approach, *Economic Theory*, 18 (1), 187–205.

Bajari, P., Houghton, S., and Tadelis, S., 2014. Bidding for Incompete Contracts, forthcoming in *American Economic Review*.

Bajari, P., McMillan, R., and Tadelis, S., 2009. Auctions versus Negotiations in Procurement: An Empirical Analysis, *Journal of Law, Economics, and Organization*, 25 (2), 372–399.

Bajari, P. and Tadelis, S., 2006. Incentives and Award Procedure: Competitive Tendering vs. Negotiations in Procurement, in N. Dimitri, G. Piga, and G. Spagnolo, eds., *Handbook of Procurement*, Cambridge University Press, 121–140.

Bajari, P. and Ye, L., 2003. Deciding between Competition and Collusion, *Review of Economics and Statistics*, 85 (4), 971–989.

Campo, S., Perrigne, I., and Vuong, Q., 2003. Asymmetry in First-Price Auctions with Affiliated Private Values, *Journal of Applied Econometrics*, 18 (2), 179–207.

Chong, E., Staropoli, C., and Yvrande-Billon, A., 2009. Auction versus Negotiation in Public Procurement: Looking for New Empirical Evidence, *Unpublished Manuscript*.

Clayton, M. and Ravid, S., 2002. The Effect of Leverage on Bidding Behavior: Theory and Evidence from the FCC Auctions, *Review of Financial Studies*, 15 (3), 723–750.

De Silva, D., Dunne, T., Kankanamge, A., and Kosmopoulou, G., 2008. The Impact of Public Information on Bidding in Highway Procurement Auctions, *European Economic Review*, 52 (1), 150–181.

De Silva, D.G., Dunne, T., Kosmopoulou, G., and Lamarche, C., 2012. Disadvantaged Business Enterprise Goals in Government Procurement Contracting: An Analysis of Bidding Behavior and Costs, *International Journal of Industrial Organization*, 30 (4), 377–388.

Guerre, E., Perrigne, I., and Vuong, Q., 2000. Optimal Nonparametric Estimation of First-Price Auctions, *Econometrica*, 68 (3), 525–574.

Haile, P., Hong, H., and Shum, M., 2006. Nonparametric Tests for Common Values at First-Price Sealed-Bid Auctions, Tech. rep.

Hong, H. and Shum, M., 2002. Increasing Competition and the Winner's Curse: Evidence from Procurement, *The Review of Economic Studies*, 69 (4), 871–898.

Iossa, E., Spagnolo, G., and Vellez, M., 2007. Contract Design in Public-Private Partnerships, *Report for the World Bank*.

Kosmopoulou, G., Lamarche, C., and Zhou, X., 2014. Price Adjustment Policies and Firm Size, *Working Paper*.

Kosmopoulou, G. and Zhou, X., 2014. Price Adjustment Policies in Procurement Contracting: An Analysis of Bidding Behavior, *Journal of Industrial Economics*, 62 (1), 77–112.

Krasnokutskaya, E., 2011. Identification and Estimation of Auction Models with Unobserved Heterogeneity, *The Review of Economic Studies*, 78 (1), 293–327.

Tadelis, S., 2012. Public Procurement Design: Lessons from the Private ector, *International Journal of Industrial Organization*, 30 (3), 297–302.

A 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.

B Technical Appendix

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,

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

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

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

This equation can be written as,

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

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

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

Simplifying we get equation (4):

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