Strategic Bidding and Contract Renegotiation

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Abstract

When firms anticipate that procurement contracts will be renegotiated after they are awarded, they will incorporate these expectations into their ex ante bidding behavior. We estimate the incidence and magnitude of strategic bidding using recent data on the bidding and renegotiation of road construction projects in Vermont. We show that firms bid higher on items whose quantities they expect to be revised upwards, and that they bid lower on items that they anticipate will have either negative quantity adjustments or price adjustments. Our structural model allows firms to predict 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. As renegotiation becomes necessary bidders seize the opportunity to impose higher markups. At the itemized level, these effects intensify with markups making up 16-18% of the bid. At the same time and in the same projects bidder lower their markups on items that are not renegotiated, creating the pattern of strategically skewed bids.

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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. The U.S. Federal Acquisition Regulation (FAR) guidelines, which dictate the available contracting options in any procurement activity using federal funds, 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 expected profits by submitting high unit prices on items expected to overrun in the future and by submitting lower unit prices on items whose actual quantity used is expected to decrease.

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 (2013) 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 probabilities of renegotiation at the item level and the need for such adjustments. First, we consider all forms of renegotiation and employ reduced form estimation to study bidding behavior while controlling for a variety of factors, including competition, local market power and for the first time in this literature, firms' debt to asset ratios. Then, we focus on a smaller, more homogeneous set of contracts 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 (2013) show that renegotiations in standard low price procurement auctions may generate significant additional transaction costs in contracting estimated to be \$2.20 for every dollar of a positive quantity adjustment in the California highway construction industry. Without the appropriate framework and structure, 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 FAR guidelines demonstrate a clear preference for simple competitive price based auction procedures. However, Tadelis and Bajari (2006) and Chong, Staropoli, and Yvrande-Billon (2009), argue that renegotiations in an award mechanism may improve upon efficiency in procurement when projects are complex or when less potential competition is expected. Bajari, McMillan, and Tadelis (2009) asserted that procurement officials should be allowed more flexibility in awarding contracts based on the characteristics of projects and bidders. Indeed, Kosmopoulou and Zhou (2013) and Zhou, Kosmopoulou, and Lamarche (2013) find that the introduction of price adjustment clauses in procurement contracting has benefited significantly the Oklahoma Department of Transportation as bids are now 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 increased 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. In order to address these concerns, we isolate a more homogeneous set of contracts and use nonparametric estimation methods similar to the ones developed by Guerre, Perrigne, and Vuong (2000) and Bajari, Houghton, and Tadelis (2013) to estimate the distribution of latent costs after controlling for the remaining project heterogeneity. We construct estimates of the markup of bids above costs, using itemized level bid information and compare how they vary across auctions with and without positive quantity renegotiation. Examining bidders' markups allows us to infer whether the anticipation of ex post renegotiation based on careful reading of plans and assessment of historical probabilities of occurrence affects strategic 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. These increases may reflect adaptation costs.

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. When controlling for project heterogeneity from observed bids including size and project types, our estimation results show that, there is little difference in firms' costs between projects that were renegotiated and projects that were not. 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 4% difference at the median and 6.4% at the mean level. Considering itemized bids, both costs and markups are increased in the treatment group 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 (18.5% on average) by 10-12% 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 overall by studies considering all forms of renegotiation.

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. 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. On average, the number of bidders and the number of prequalified plan-holders are 3.349 and 5.026 per auction, respectively. The number of different items in the contract has been used as a proxy for project complexity. The average number of items per contract is 60. Winning bids on renegotiated

[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.

[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	Observation	Mean	Standard Deviation	Min	Max
Itemized Relative Bid (before Change Orders)	50,465	1.162	0.673	0.000	4.000
Itemized Bidding Amount (in millions)	50,465	\$0.028	\$0.124	\$0.000	\$5.077
Relative Bid (before Change Orders: (Bid / Engineering Cost Estimate)	857	1.092	0.277	0.500	2.339
Bidding Amount (in millions)	857	1.723	2.282	0.025	29.505
Bidders (per Contract)	312	3.349	1.959	1.000	11.000
Plan-holder (per Contract)	312	5.026	3.163	1.000	16.000
Complexity (Number of Distinct Items per Contract)	312	60.228	35.346	2.000	245.000
Winning Bid Amount (in millions)	312	\$1.806	\$2.260	\$0.025	\$21.983
Engineering Cost Estimate of the Winning Contract (in millions)	312	\$1.910	\$2.432	\$0.026	\$24.552
Change Orders Amount (in millions)	256	\$0.174	\$0.323	-\$0.117	\$2.331
Relative Winning Bid (before Change Orders)	256	0.977	0.190	0.436	1.564
Relative Payment Amount (after Change Orders)	256	1.056	0.228	0.532	2.014
Positive Quantity Adjustment(in millions)	185	\$0.154	\$0.225	\$0.000	\$1.259
New Added Item Amount (in millions)	222	\$0.149	\$0.312	\$0.000	\$2.689
Price Adjustment Amount (in millions)	41	\$0.221	\$0.240	\$0.006	\$1.047
Negative Quantity Adjustment Amount (in millions)	87	-\$0.119	\$0.295	-\$2.266	-\$0.000
Dropped Item Amount (in millions)	130	-\$0.122	\$0.250	-\$1.591	-\$0.000

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. 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), followed by positive quantity adjustments (72.27% of projects). 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 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.

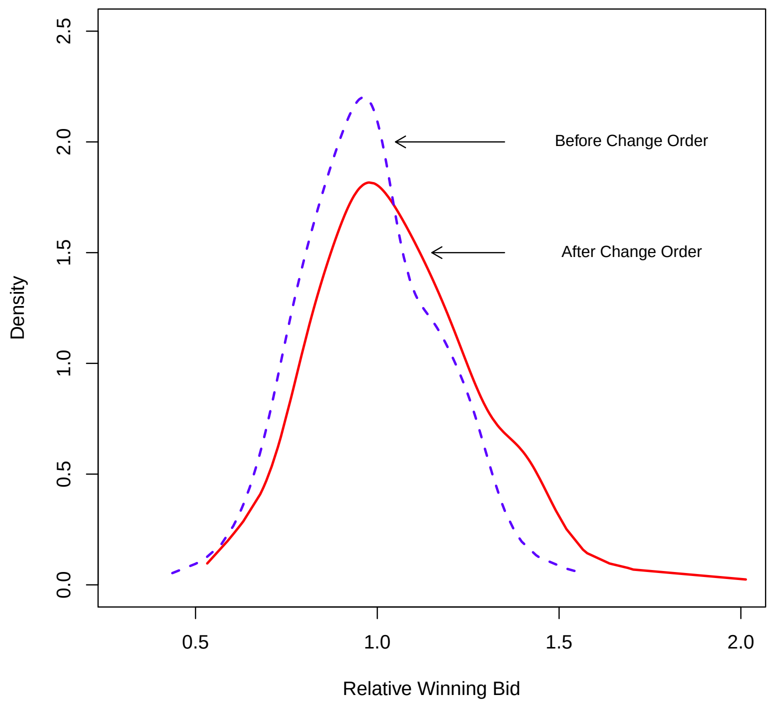

Figure 1: Kernel Density Plot of Relative Winning Bids

Figure 1 is a kernel density plot 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 type of adjustments presents vastly different challenges for the Transportation agencies. Price adjustments are based on a market based index[4] that is independent of firms' reported bids. In contrast, quantity adjustments lead to direct bid skewness that is not observed in the presence of other types of change orders, and merit more attention. Our goal is to investigate whether there are indeed distinct effects that are more prominent when quantity adjustments become commonplace.

[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 even though they could be positive or negative.

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 at the project level the dependent variable is the logarithm of bid submitted by bidder i, in auction a, in month t. The independent variables include 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 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 estimate of the engineering cost 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 elevation captures related differences in the work site conditions. The variable expected number of bidders controls for differences in competition by incorporating the probability that a plan-holder will participate in the auction letting.[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. The information allows us to measure business strength and capacity more accurately, rather than

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

resorting to local workloads as a proxy of firm activity based on state-level data.[6] 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. Zhou, Kosmopoulou, and Lamarche (2013) also show that smaller, typically financially constrained firms react positively to risk reduction measures.

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.[7] 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 the top firm dummy. 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. Larger values are associated with a firm having a dominant position in that county. It is also important to control for factors that affect the general economic conditions. Finally, we include two control variables, namely, the three month average of the number of building permits issued in the state and the unemployment rate to capture the local business climate.

Notice that we also use different sample sizes in this reduced form analysis. In particular, we estimate the model with a subsample of only the projects used in our structural estimation later to investigate whether the treatment effect in the subsample is randomly assigned conditional on other control variables. We estimate the models using ordinary least squares (OLS) with clustered

[6]We might keep in mind that Vermont is a smaller state and almost half of the headquarters of contractors are located outside the state. Without knowing their business activity out of state we will not be able to assess the effect of their capacity constraints on bidding.

[7]Note that the highway construction market is highly concentrated in Vermont. Based on 15% revenue threshold used in our analysis, we assign, on average, only 10% (6 firms per year) of the total firms in the market as top firms. The threshold allows us to separate firms with higher and lower probability of winning. The probability of winning for top firms is on average 38.03% which is 9.46% higher than the rest of the firms considered. This difference is similar to that in Bajari, Houghton, and Tadelis (2013), showing an 11.60% difference across groups. The probability of winning for top firms is 8.07% higher in our case due to high market concentration.

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. 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 of an itemized bid during the period of analysis. We use similar control variables as in the project level specifications but for this itemized bid analysis we include item fixed effects to capture different characteristics of tasks.[8] 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 709 different items used during the sample period. Of those, 368 items never appear on a change order.

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 (2013), who postulate that price adjustment clauses that are based on an index may produce direct cost benefits 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. Bidding strategies eventually cause an increase in payments.

The coefficient on the ex post positive quantity adjustment amount is 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 payments. By doing so, bidders increase the probability of winning the project, and later recover their forgone profits. This is consistent with theory (see Athey and Levin (2001)). The engineering cost estimate and the log of calendar days have the expected impact on their bid. In particular, the engineer cost estimates

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

Table 2: Regression Results for a Model of Bids

	Project Bids			Subsample	Itemized Bids
Independent Variable	(1)	(2)	(3)	(4)	(5)
Price Adjustment	-0.198*	-0.276**			-0.203**
	(0.107)	(0.108)			(0.080)
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)
Dropped Item Amount	-0.199	-0.244*			-0.007**
	(0.129)	(0.130)			(0.004)
New Added Item Amount	-0.091	-0.134			0.048***
	(0.116)	(0.115)			(0.017)
Change Order Indicator	-	-	0.072***	-0.050	-
	-	-	(0.027)	(0.043)	-
Log of Engineer's Estimate	0.916***	0.888***	0.858***	0.852***	0.898***
	(0.017)	(0.018)	(0.017)	(0.038)	(0.005)
Log of Calendar Days	0.065***	0.086***	0.090***	0.040	0.036**
	(0.029)	(0.027)	(0.023)	(0.045)	(0.016)
Complexity	0.053	0.022	0.099	0.331**	-0.005
	(0.073)	(0.071)	(0.068)	(0.135)	(0.033)
Expected Number of Bidders	-0.016***	-0.020***	-0.033***	-0.066	-0.024***
	(0.006)	(0.006)	(0.005)	(0.052)	(0.004)
Distance to the Project Location	-0.002	-0.020	-0.003	-0.043	0.017
	(0.022)	(0.031)	(0.032)	(0.064)	(0.021)
Rival's Minimum Distance to	-0.019	0.032	0.045	-0.063	-0.015
the Project Location	(0.030)	(0.034)	(0.034)	(0.063)	(0.030)
Top Firm	-0.030	-0.017	0.029	0.016	-0.085***
	(0.028)	(0.037)	(0.035)	(0.059)	(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	Yes	Yes	Yes
Firm Fixed Effects (55)	No	Yes	Yes	Yes	Yes
Item Fixed Effects (709)	No	No	No	No	Yes
Observations	857	857	857	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.

explains almost all of the variation in our dependent variables. As Tadelis (2012) mentioned in his recent paper, more complex projects are expected to experience ex post renegotiations in fixed price contracts due to contractual incompleteness. Bidders are more likely to incorporate the risk premium of 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. 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.

Among the variables controlling for bidder's relative advantage and strength of an opponent in cost, 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. The elevation of work site is statistically significant and positive 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 variable is small in this case, perhaps showing that the contractual commitment of firms in Vermont relative to their overall workload could be small.

The 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 an auction is much higher for firms during the 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 as an alternative 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. To examine the impact of contract renegotiation on strategic bidding, it is crucial to control for the competitive environment and projects' 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 (2013). 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 bidder observable variables such as firm's distance to project location and a variable indicating whether a bidder is a top firm. In this study, we overcome selection issues by using subsets of projects with and without renegotiations. We refer the reader to Subsection 4.2 where we explain in detail how we obtain subsets of homogeneous projects. As mentioned before, the variable that indicates a change order is significant when the model is estimated considering all heterogeneous projects, although the indicator variable is no longer statistically significant when we use a subsample of homogeneous projects. This result suggests that a change order is randomly assigned conditional on observable covariates, provided that a selected sample of homogeneous projects is employed in the analysis.

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), Bajari, Houghton, and Tadelis (2013).

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 *iid*. The asymmetries may arise from different capacity constraints, distances to the work sites, cost efficiency level, or working experiences across firms. 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 Haile, Hong, and Shum (2006), Bajari, Houghton, and Tadelis (2013), and Guerre, Perrigne, and Vuong (2000) 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 bidder i's 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 (2013) which assumes 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 additional work is needed. Although bidders might not have exact information on the probability of renegotiation, they can form expectations about future adjustments on each item based on its historical probability of renegotiations and the necessity of ex post renegotiations due to incomplete project plans. 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:

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

$$= \left[\mathbf{b}^i \cdot (\mathbf{k} \cdot \mathbf{q}^a + (\mathbb{1} - \mathbf{k}) \cdot \mathbf{q}^e) - \mathbf{c}^i \cdot (\mathbf{k} \cdot \mathbf{q}_t^a + (\mathbb{1} - \mathbf{k}) \cdot \mathbf{q}^e)\right] \times \left[\prod_{j \neq i} (1 - H_j(s^i))\right] \tag{3}$$

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:

$$\frac{\partial \pi^i(\mathbf{b}^i, \mathbf{c}^i, \mathbf{k})}{\partial b_t^i} = (\mathbf{k} \cdot \mathbf{q}^a + (\mathbb{1} - \mathbf{k}) \cdot \mathbf{q}^e) \left[\prod_{j \neq i} (1 - H_j(s^i))\right] - \left[\mathbf{b}^i \cdot (\mathbf{k} \cdot \mathbf{q}^a + (\mathbb{1} - \mathbf{k}) \cdot \mathbf{q}^e)\right.$$
$$\left. - \mathbf{c}^i \cdot (\mathbf{k} \cdot \mathbf{q}^a + (\mathbb{1} - \mathbf{k}) \cdot \mathbf{q}^e)\right] \times \left[q_t^e \sum_{k \neq i} h_k(s^i) \prod_{j \neq i,k} (1 - H_j(s^i))\right] = 0. \tag{4}$$

Because $\left[q_t^e \sum_{k \neq i} h_k(s^i) \times \prod_{j \neq i,k} (1 - H_j(s^i))\right]$ 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, we write the first order condition as,

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

Equation (5) is expressing the FOC as a function of the probability, k_t, that item t is renegotiated. If $k_t = 0$ for all task t, then equation (5) can be written as follows:

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

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

$$(\mathbf{b}^i - \mathbf{c}^i) \cdot \tilde{\mathbf{q}}^a = \left(\frac{k_t q_t^a + (1-k_t) q_t^e}{q_t^e}\right) \left(\sum_{j \neq i} \frac{h_j(s^i)}{(1 - H_j(s^i))}\right)^{-1} \tag{7}$$

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 Selected Sample Data

The estimation of equations (6) and (7) require a sample of projects that have a relatively similar set of tasks and fit the IPV model. We further restrict our attention to more homogeneous projects in road/highway contracts with 2 or 3 bidders. As De Silva, Dunne, Kankanamge, and Kosmopoulou (2008) discuss in details, the individual bidder's efficiency level is more critical to determine its cost in asphalt projects. We analyze the road/highway projects as the subsample for the IPV setting. The sample selection is justified by the fact that bidders can estimate more accurately their costs for those projects than those for bridge projects which are typically studied in a common value setting (see also Hong and Shum (2002) and De Silva, Dunne, Kankanamge, and Kosmopoulou (2008)). Furthermore, we restricted the sample to projects with project values between \$200,000 and \$5 million.

In our analysis the treatment group consists of projects with positive quantity adjustments and the comparison group is containing projects in which there is no positive quantity adjustment. We use two different variants of the control group. The comparison group "A" contains new added item adjustments and dropped items but no positive or negative quantity adjustments, whereas comparison group "B" contains projects with no renegotiation at all. The descriptive statistics for these three groups are presented in Table 3. Notice that, the size and number of tasks are notably different across projects in these samples in spite of our relative homogenization. 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.

In comparing bid distributions of projects with renegotiated items and with no renegotiated

Table 3: Comparison of Summary Statistics across Projects

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

Table 4: Comparison of Summary Statistics for Pay Items

			Bid Price				Itemized Bid Amount (in $10000)			
Pay Items	Group	Obs	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
406.25	Treatment	5	62.640	8.503	52.520	70.000	99.906	32.666	58.297	133.000
	Control A	15	91.476	33.911	49.000	168.000	17.120	12.608	2.720	39.900
	Control B	12	84.095	28.927	49.000	138.000	20.432	11.922	8.125	39.900
490.30	Treatment	13	79.309	38.232	42.000	165.000	141.483	81.300	25.336	313.425
	Control A	28	72.593	19.527	44.500	110.000	80.089	47.614	27.000	187.395
	Control B	15	72.570	19.141	44.500	110.000	79.595	59.325	27.000	187.395
617.10	Treatment	3	230.833	80.480	142.500	300.000	0.023	0.008	0.014	0.030
	Control A	6	177.500	59.812	120.000	250.000	0.039	0.020	0.018	0.075
	Control B	4	160.000	61.644	120.000	250.000	0.048	0.018	0.036	0.075
621.90	Treatment	2	62.500	31.820	40.000	85.000	0.375	0.191	0.240	0.510
	Control A	5	40.200	18.714	20.000	66.000	3.906	2.343	1.400	6.930
	Control B	2	22.500	3.536	20.000	25.000	1.575	0.247	1.400	1.750
630.15	Treatment	5	30.590	14.492	22.500	56.450	6.718	4.359	3.375	14.113
	Control A	69	20.865	10.743	1.000	63.000	3.199	3.724	0.050	17.550
	Control B	37	19.868	11.509	1.000	63.000	2.075	2.573	0.050	11.374
646.85	Treatment	2	0.670	0.113	0.590	0.750	1.695	0.286	1.493	1.898
	Control A	22	2.027	1.413	0.300	5.000	0.934	1.719	0.012	5.704
	Control B	16	1.969	1.214	0.700	5.000	0.759	1.797	0.012	5.704

items, item heterogeneity is a challenging issue. However, our data allows us to identify a selected group of items that were renegotiated with positive probability. Moreover, because 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. In particular, we select for the analysis six items as shown in Table 4 and focus on their cost estimates or their markups at the itemized level.[9] Those items have positive quantity adjustments in the treatment group. Then, we select the same tasks in contracts within the control group. Notice that the itemized bid prices are much more similar while the itemized bid amounts are significantly different across items between the two groups.

3.3 Nonparametric estimation

This section follows closely Bajari, Houghton, and Tadelis (2013), 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 characteristics and bidders specific characteristics:

$$y_{rj}^{(m_r)} \equiv \mathbf{b}_{rj}^{(m_r)} \cdot \mathbf{q}^{e(m_r)} = \boldsymbol{\mu}'\mathbf{x}_{rj}^{(m_r)} + \boldsymbol{\theta}'\mathbf{z}^{(m_r)} + \varepsilon_{rj}^{(m_r)} \tag{8}$$

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, top firm indicator, 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.

[9] Each pay item description is as follows; 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.

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

Recall that $s^i = \mathbf{b}^i\mathbf{q}^e$ and that the cumulative distribution function of contractor j is defined $H_j(s^i) \equiv Pr(\mathbf{b}_j\mathbf{q}^e \leq s^i)$. Using equation (8) 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:

$$H_{rj}^{(m_r)}(b) = Pr\left(\boldsymbol{\mu}'\mathbf{x}_{rj}^{(m_r)} + \boldsymbol{\theta}'\mathbf{z}^{(m_r)} + \varepsilon_{rj}^{(m_r)} \leq s_r^i\right) \equiv G\left(b_{rj}^{(m_r)}\right), \tag{9}$$

where $b_{rj}^{(m_r)} = s_r^i - \boldsymbol{\mu}'\mathbf{x}_{rj}^{(m_r)} - \boldsymbol{\theta}'\mathbf{z}^{(m_r)}$. Under i.i.d. assumptions on the error term ε, we estimate equation (8) using standard parametric models, obtain the residuals, $\widehat{\varepsilon}_{rj}^{(m_r)}$, and use $\widehat{\varepsilon}_{rj}$ to estimate the density $h_{rj}(\cdot)$ and the probability distribution function $H_{rj}(\cdot)$. 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 $\widehat{\varepsilon}_{rj}^{(m_r)}$, κ $= 2.9878 \times 1.06$, and L_{rj} is the number of auctions in which a bidder j participated.

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 $\mathbf{c}_1^i$,

$$(\mathbf{b}_0^i - \mathbf{c}_0^i) \cdot \tilde{\mathbf{q}}^e = \left(\sum_{j \neq i} \frac{\hat{h}_{0j}(s^i)}{(1 - \hat{H}_{0j}(s^i))}\right)^{-1} \tag{10}$$

$$(\mathbf{b}_1^i - \mathbf{c}_1^i) \cdot \hat{\mathbf{q}}^a = \left(\frac{\hat{k}_t q_t^a + (1-\hat{k}_t) q_t^e}{q_t^e}\right)\left(\sum_{j \neq i} \frac{\hat{h}_{1j}(s^i)}{(1 - \hat{H}_{1j}(s^i))}\right)^{-1} \tag{11}$$

where $\hat{k}_t$ is an estimate of the probability of renegotiation and $\hat{\mathbf{q}}^a = \hat{\mathbf{k}}(\mathbf{q}^a - \mathbf{q}^e) + \mathbf{q}^e$. 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 average historical probability of positive quantity adjustments for an item is 4.08% with a standard deviation of 5.74% during the sample period. These probabilities range from 2 percent to 28 percent.

We denote the solution of equations (10) and (11) by $\hat{\mathbf{c}} = (\hat{\mathbf{c}}_0', \hat{\mathbf{c}}_1')'$ which represent pseudo-values of the cost of projects with ex post renegotiations and the cost of projects without ex post renegotiations. In the next section, we estimate density functions using the sample of pseudo-values, without any assumption regarding a specific functional form.

3.4 Estimation of project costs

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 item adjustments and dropped items (comparison group A) and the right panel presents the estimated cost densities of projects with no renegotiation at all (comparison group 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.

Markups over production costs could be associated with the risk premium for project uncertainty and rents obtained by strategic bidding adjustments consistent with asymmetric knowledge. 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 (2013) 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 ex post payments, the estimated markup drops to 3.7% for all bids and 12.52% for winning bids. The results imply that the previous literature might have mis-specified markups because it failed to take into account the outcomes of renegotiations.

In Table 5, we summarize our estimates of bidders' markups over estimated costs for projects

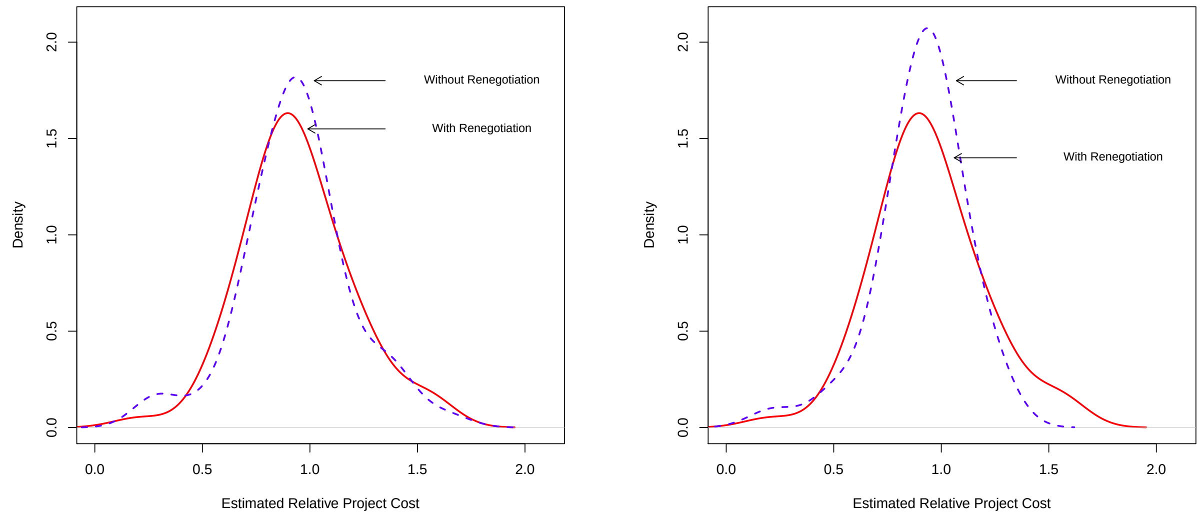

Figure 2: Relative cost in projects with and without renegotiation using control groups A (left panel) and B (right panel)

with and without positive quantity renegotiations after controlling for unobserved heterogeneity.[10] 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 (2013). 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 relatively higher than those reported in Bajari, Houghton, and Tadelis (2013). 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. Table 5 suggests a difference of 4-5% at the median level between markups in contracts with and without renegotiation.

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

Table 5: Markups for projects with and without renegotiation

Group	20%	30%	40%	50%	60%	70%	80%
With Renegotiation (Treatment)	2.532	4.072	7.476	8.695	12.300	15.090	17.400
Without Renegotiation (Control A)	2.594	3.318	4.070	5.750	7.956	9.174	13.500
Without Renegotiation (Control B)	1.702	2.310	3.562	4.610	7.072	9.194	11.760

3.5 Estimation of itemized costs

It is well known in the empirical auction literature that bidder asymmetry within the IPV setting has no analytical solution due to an intractable system of first order conditions. It is also known and immediately apparent in Table 3 that item heterogeneity is a crucial determinant of whether an item is renegotiated. An empirical identification strategy that fail to address it cannot offer credible evidence on the effect of renegotiation on bidding patterns and costs. Under the assumption is 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 (6) for projects with $k_t = 0\ \forall t$ as,

$$\mathbf{c}_0^i \cdot \mathbf{q}_0^e = \mathbf{b}_0^i \cdot \mathbf{q}_0^e - \left(\sum_{j \neq i} \frac{h_{0,j}(s_0^i)}{(1 - H_{0,j}(s_0^i))} \right)^{-1}. \tag{12}$$

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 (12) for projects with no renegotiated items by separating items into two groups, $t = 1, ...m$ and $t = m + 1, ...T$,

$$\sum_{t=m+1}^{T} (b_{0,t}^i - c_{0,t}^i) q_{0,t}^e = \sum_{t=1}^{m} c_{0,t}^i q_{0,t}^e - \sum_{t=1}^{m} b_{0,t}^i q_{0,t}^e + \left(\sum_{j \neq i} \frac{h_{0,j}(s_0^i)}{(1 - H_{0,j}(s_0^i))} \right)^{-1}, \tag{13}$$

where the left hand side of equation (13) denotes tasks that are not renegotiated in other projects that can include renegotiated items. Moreover, equation (7) is equivalent to,

$$\left[\sum_{t=1}^{m} (b_{1,t}^i - c_{1,t}^i) \tilde{q}_{1,t}^a + \sum_{t=m+1}^{T} (b_{1,t}^i - c_{1,t}^i) q_{1,t}^e \right] = \left(\frac{k_t q_t^a + (1 - k_t) q_t^e}{q_t^e} \right) \left(\sum_{j \neq i} \frac{h_{1,j}(s^i)}{(1 - H_{1,j}(s^i))} \right)^{-1}. \tag{14}$$

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

$$\sum_{t=m+1}^{T}(b^i_{0,t}-c^i_{0,t})q^e_{0,t}=\sum_{t=m+1}^{T}(b^i_{1,t}-c^i_{1,t})q^e_{1,t}, \tag{15}$$

suggesting that we can substitute equation (13) in the second term in the left hand side of equation (14). After some algebra, it is possible to evaluate the total cost distribution for the group of renegotiated items as follows,

$$\begin{aligned}\sum_{t=1}^{m}c^i_{1,t}q^a_{1,t}=&\sum_{t=1}^{m}b^i_{1,t}\tilde{q}^a_{1,t}+\left[\left(\sum_{j\neq i}\frac{h_{0,j}(s^i_0)}{(1-H_{0,j}(s^i_0))}\right)^{-1}-\sum_{t=1}^{m}b^i_{0,t}q^e_{0,t}+\sum_{t=1}^{m}c^i_{0,t}q^e_{0,t}\right]\\&-\left[\left(\frac{k_t q^a_{1,t}+(1-k_t)q^e_{1,t}}{q^e_{1,t}}\right)\left(\sum_{j\neq i}\frac{h_{1,j}(s^i_1)}{(1-H_{1,j}(s^i_1))}\right)^{-1}\right].\end{aligned} \tag{16}$$

To uncover the cost of renegotiated items, $(c_{1,1},\ldots,c_{1,m})$, we first estimate the left hand side of equation (12) and then we use these estimates to obtain the left hand side of equation (16). Using the procedure introduced in Section 3.1, we can similarly obtain $\hat{h}_{0,j}$, $\hat{h}_{1,j}$, $\hat{H}_{0,j}$, $\hat{H}_{1,j}$, $\hat{k}_t$, and $\hat{q}^a_t$. To estimate $(c_{0,1},\ldots,c_{0,m})$, we first obtain $\hat{\mathbf{c}}_0$ from equation (12) and then obtain, $\hat{c}^i_{0,t}=b^i_{0,t}q^e_{0,t}\hat{\mathbf{c}}_0/s^i_0$ for $t=1,\ldots,m$. Each itemized cost in the control group is constructed as the proportional amount of total project cost estimates using the ratio of the itemized bid amount to the bid amounts in the control group. Those items experienced no renegotiations in the control group while they were renegotiated in contracts of the treatment group.

We present our results for estimating the itemized cost distribution in Figure 3. The left panel offers results using the set of items in comparison group "A", and the panel on the right offers results using the set of items in comparison group "B". Figure 3 shows the itemized unit-cost estimates of different types of items. It shows that there are significant cost differences between types indicating the location shift to the right for the distribution of renegotiated items. The itemized cost estimates with renegotiations (shown as a solid line) in the figures are obtained using control group "A" in which there are two types of adjustments and control group "B" of the projects without any adjustments. These figures imply that our results are robust because the distributions of cost estimates for renegotiated items are very similar to each other even if we use different types of control groups.

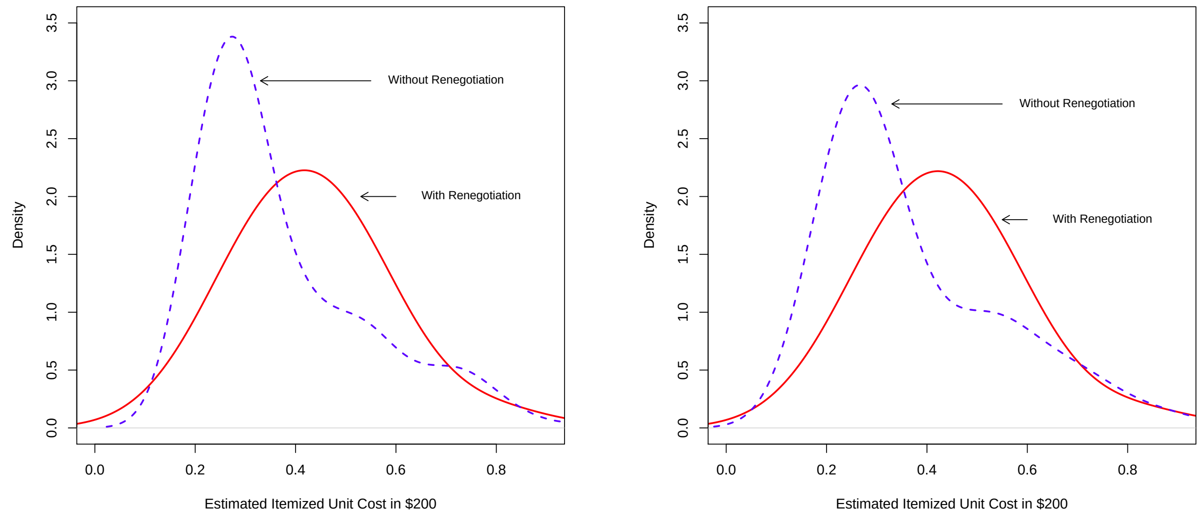

Figure 3: Itemized Unit Cost distribution for Items with and without renegotiation using control groups A (left panel) and B (right panel)

It is important to note that we obtain different itemized cost estimates in the treatment group depending on the type of control group we use to estimate it. 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 or firm heterogeneity because we use firm and item specific cost estimates from the control group to estimate its itemized cost in the treatment group.

Table 6 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. The mean markup for renegotiated items is about 16% - 18% which is much higher than that at the project level. On the other hand, the mean markup for items that are not renegotiated is similar to that at the project level.

Lastly, we are able to estimate the markups for items that are not renegotiated in contracts that have renegotiated items. We compare them with markups for the same set of items in contracts that have no renegotiated items. We first 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

Table 6: Markups for items with and without renegotiation

Group	20%	30%	40%	50%	60%	70%	80%
With renegotiation (Treatment)	7.319	11.510	13.720	17.900	21.950	22.760	31.470
Without renegotiation (Control A)	2.763	3.603	4.188	7.000	8.195	9.232	13.540
With renegotiation (Treatment)	4.138	10.760	11.920	16.300	17.600	19.900	28.440
Without renegotiation (Control B)	1.751	2.530	4.156	4.986	7.302	10.023	12.430

Table 7: Markups for non-renegotiated items in projects with renegotiation

Group	20%	30%	40%	50%	60%	70%	80%
No renegotiated item in renegotiated project	0.113	1.227	1.658	5.659	7.413	8.966	9.015
No renegotiated item (Control A')	1.783	3.326	3.938	5.928	7.327	8.335	9.232
No renegotiated item in renegotiated project	1.309	1.492	3.828	3.906	6.167	7.073	14.144
No renegotiated item (Control B')	1.482	2.149	3.987	4.661	6.906	9.017	9.885

project by using the remaining cost estimate and the ratio of the itemized bid amount. In Table 7, we summarize our estimated markups of those items across groups.[11]

This table implies that renegotiating 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 Table 6, and they are slightly lower than the markups in the control groups A' and B'. Notice that the items in the projects without renegotiations have comparable markups as those reported in Table 6. The pattern of strategically skewed bidding revealed here is consistent with those in Athey and Levin (2001) adjusting for different expectations. The sole exception is the comparison of markups at the upper quantile between the treatment and control group B'. The results are robust to alternative specifications across the groups.

3.6 Testing the cost distribution invariance

This section briefly 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

[11] After defining the set of non renegotiated items in contracts with renegotiations, we found 155 items in control group A' and 39 items in control group B'. The reason why we use the different number of items is that the former consists of almost twice more projects than the latter as shown in subsection 4.2.

Table 8: Tests for invariance of cost distributions to renegotiations

		With Renegotiation			Without Renegotiation			Tests
Control Group	Estimated Costs	Median	Mean	SD	Median	Mean	SD	(KS)
A	Relative Project Cost	0.908	0.941	0.253	0.928	0.936	0.259	0.955
	Itemized Unit Cost (in $200)	0.223	0.232	0.134	0.108	0.176	0.172	0.022
B	Relative Project Cost	0.908	0.941	0.253	0.936	0.906	0.204	0.558
	Itemized Unit Cost (in $200)	0.224	0.237	0.137	0.095	0.174	0.174	0.003

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

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 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.

3.7 Counterfactuals

This subsection conducts 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%. 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 the 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 when the probability of renegotiation changes marginally. The solid red line indicates the estimated

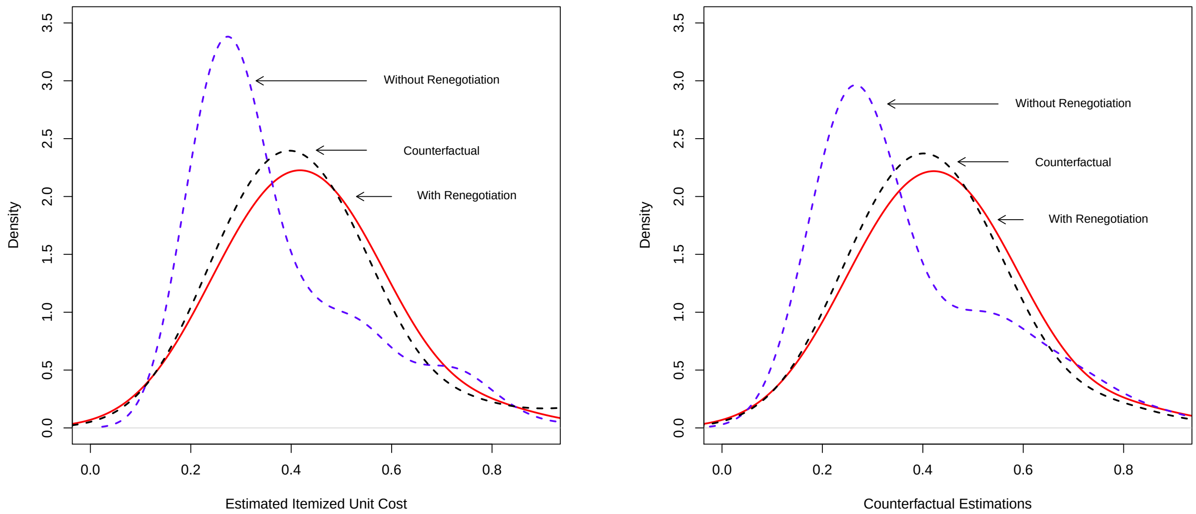

Figure 4: Counterfactual estimations for itemized costs using control groups A (left) and B (right)

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 (16), 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 (Tables 9 and 10). We find that a 5% decrease in probability of renegotiation could cause itemized costs to decrease by 7.06% - 7.24% at the mean level, depending on our control groups. 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, contractor's markups are systematically decreased through its strategic reaction. These results are largely consistent with our previous finding that bidders impose higher markups on items that are renegotiated.

Table 9: Expected Payments and Estimated Costs: (An Item level)

	Renegotiation			Counterfactual		
	Median	Mean	SD	Median	Mean	SD
Estimated Itemized Costs (in $10,000) (using Control Group A)	79.750	71.640	66.743	72.760	66.450	62.584
Estimated Itemized Costs (in $10,000) (using Control Group B)	82.150	73.650	68.221	75.157	68.450	64.037

Table 10: Estimated Itemized Markups under Counterfactual

Group		20(%)	30(%)	40(%)	50(%)	60(%)	70(%)	80(%)
Counterfactual	(using control group A)	0.331	9.743	11.744	14.938	23.638	29.747	30.524
Treatment		7.319	11.510	13.720	17.900	21.950	22.760	31.470
Counterfactual	(using control group B)	0.162	4.868	10.054	12.403	18.713	21.485	26.542
Treatment		4.138	10.760	11.920	16.300	17.600	19.900	28.440

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. In particular, we present strong 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 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 also show that firms strategically reduce their bids and markups on other items in the same contract. The evidence of unbalanced or "skewed" itemized bidding is based on a carefully constructed homogeneous subsample of projects and provides strong support for the basic conclusions of Athey and Levin (2001). 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 perhaps their own competitors, and are able to exploit these advantages in order to add to their own profitability. Bid skeweness could be avoided and profit margins could perhaps be restricted 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 (2013), in that we estimate increases in project costs associated with contract renegotiations. Our counterfactual exercise indicates that as the probability of renegotiation increases, the estimated itemized costs also increase. 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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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 $ million). 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 $ million).
Negative Quantity Adjustment	Ex post total negative quantity adjustment amount in the project (in $ million).
Dropped Item Amount	The total value of dropped items from the original contract (in $ million).
New Added Item Amount	The total value of new added items in the project (in $ million).
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 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 as 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 Derivations

We assume that there are 4 bidders such as i, j, k and l to show how we derived equation (5). Equation (3) 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

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

This equation can be written as,

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

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 (5):

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