UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

THREE ESSAYS ON CONTRACT RENEGOTIATION

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

Degree of

DOCTOR OF PHILOSOPHY

By

HOJIN JUNG
Norman, Oklahoma
2014

THREE ESSAYS ON CONTRACT RENEGOTIATION

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF ECONOMICS

BY

Dr. Georgia Kosmopoulou, Chair

Dr. Gregory Burge

Dr. Qihong Liu

Dr. Cynthia Rogers

Dr. Scott Linn

Acknowledgements

Throughout the process of writing my dissertation, I received invaluable support from many people. My advisor, Dr. Georgia Kosmopoulou, was always available to offer input and suggestions that is reflected throughout this work. For this, I am extremely thankful. I also received frequent input from the dissertation committee including Dr. Gregory Burge, Dr. Qihong Liu, Dr. Cynthia Rogers, and Dr. Scott Linn. Each of these people has been instrumental in this effort, and I am extremely appreciative of the time they spent with me.

I am particularly grateful to Dr. Carlos Lamarche and Dr. Richard Sicotte for their extremely patient help and enthusiastic motivation. I am indebted to the staff at Vermont Agency of Transportation for providing useful information. Last but certainly not in the least, a great appreciation goes to Nancy Allard, DCSW, Dr. Li Su, Dr. Michael Walker, and my family for their invaluable help during my graduate study.

Table of Contents

1 Introduction **1**

1.1 An Overview . . . 1

1.2 Literature on Procurement Auction with Renegotiation . . . 4

2 Strategic Bidding and Contract Renegotiation **11**

2.1 Introduction . . . 11

2.2 Data and summary statistics . . . 15

2.2.1 An overview of change orders on Vermont transportation contracts . . . 15

2.2.2 Reduced form estimation . . . 19

2.3 Structural Estimation . . . 29

2.3.1 Equilibrium bidding behavior . . . 29

2.3.2 Nonparametric estimation . . . 31

2.3.3 Data . . . 34

2.3.4 Estimation results for project costs and markups . . . 38

2.3.5 Estimation of itemized costs . . . 40

2.3.6 Testing the cost distribution invariance . . . 45

2.3.7 Counterfactuals . . . 46

2.4 Conclusion . . . 48

3 Renegotiation on Incomplete Procurement Contracts **50**

3.1 Introduction . . . 50

3.2 Data and summary statistics . . . 54

3.3 Empirical Analysis . . . 61

3.3.1 Equilibrium bidding behavior . . . 61

3.3.2 Selected sample data . . . 64

3.3.3 Reduced form estimation . . . 66

3.3.4 Structural estimation . . . 69

3.3.5 Adaptation cost and time delays . . . 73

3.3.6 Robustness checks . . . 75

3.4 Conclusion . . . 78

4 Uncertainty and Contract Renegotiation in Public Procurement **80**

4.1 Introduction . . . 80

4.2 Data and Descriptive Analysis . . . 82

4.3 Empirical Analysis 86
4.4 Conclusion 97

5 Conclusions **98**

Bibliography **100**

Appendix A Regression Variables **105**

Appendix B Technical Appendix **108**

List of Figures

2.1 Kernel Density Plot of Relative Winning Bids 18
2.2 Relative cost in projects with and without renegotiation 39
2.3 Itemized Unit Cost distribution for items with and without renegotiation 43
2.4 Counterfactual estimations for itemized costs 47

3.1 Project with Extra Work Location and Average Number of Items added in the Vermont Transportation Construction Industry 55
3.2 Propensity to experience extra work adjustments 56
3.3 Density distribution function of relative bids 60
3.4 Relative cost in projects with and without renegotiation 72
3.5 Robustness Checks: Relative cost in projects with and without renegotiation 77

4.1 Project Locations and Change Orders in the Vermont Highway Construction Industry 83
4.2 Histograms of the Number of Change Orders and the Ratio of Change Order Amounts to Winning Bids 86

List of Tables

2.1 Descriptive Statistics 16
2.2 Regression Results for a Model of Bids 22
2.3 Probabilities of Renegotiation for Pay Items 28
2.4 Comparison of Summary Statistics across Projects 35
2.5 Comparison of Summary Statistics for Pay Items 37
2.6 Markups for projects with and without renegotiation 40
2.7 Markups for items with and without renegotiation 44
2.8 Tests for invariance of cost distributions to renegotiations 46
2.9 An Analysis of Estimated Costs 47

3.1 Descriptive Statistics 57
3.2 Summary statistics of contracts by year of award 59
3.3 Summary statistics of contracts by project type 59
3.4 Data Description 65
3.5 Regression Results for a Model of Bids 68
3.6 Markups for projects with and without renegotiation 73
3.7 Tests for invariance of cost distributions to renegotiations 73
3.8 Adaptation costs and time delays of project with extra work adjustment 75
3.9 Robustness Checks: Tests for invariance of cost distributions to renegotiations 76
3.10 Summary statistics by number of bidders 76

4.1 Bidding and renegotiation activities of 92 firms 85
4.2 Estimation results 89
4.3 Comparison of MLT between fringe firms and top firms (310 projects) 93
4.4 Estimation results 95
4.5 Estimation results 96

Abstract

This dissertation is a collection of three essays investigating renegotiation of procurement auctions in the road construction industry. The empirical analysis uses contracts procured by the Vermont Agency of Transportation from 2004 to 2009. In practice, these adjustments, frequently attributed to incomplete contracts, are observed in sizable and complex procurement projects. As a consequence there are significant differences between contract amounts and final payments to a contractor due to ex post changes. In addition, it is possible that firm's bidding strategies are influenced by the anticipation of change orders, with negative effects on the efficiency and overall cost of highway construction programs. First we investigate the impacts of ex post renegotiations on ex ante bidders' bidding behaviors and their markups and costs. In particular, we consider a set of adjustment types such as quantity adjustments and extra work adjustments which are common in the field. Then we analyze the factors associated with the frequency of change orders.

In the first essay, we focus on ex ante bidder's strategic bidding behavior in anticipation of ex post contract renegotiation. The empirical analysis shows that the magnitude of estimated markups is systematically higher for projects with positive quantity adjustments than those without such renegotiations. The second essay continues the study of the impact of incomplete contracts that requires ex post extra work on procurement costs. We find this unique compensation process causes significant adaptation costs at the renegotiation stage, which provides contractors

with markups similar to those they would earn in projects without renegotiations at all. In the last essay, we investigate the reasons for the frequency and magnitude of renegotiations in the Vermont transportation contracts. We show that project uncertainty and complexity and bidding behaviors are valuable predictors of renegotiations.

All these studies are about public procurement in the transportation industry. Every essay provides a transportation department with relevant policy implications. This study has the potential to increase the efficiency of budgetary planning for the transportation department, and reduce costs to the tax payers. Our empirical analysis shows that bidder's strategic bidding and adaptation costs associated with renegotiating a contract could increase the procurement costs. Therefore, it may be preferable for the procuring agency to invest more time in providing more completed designs rather than to proceed with the project and deal with renegotiations ex post.

Chapter 1

Introduction

1.1 An Overview

Public procurement accounts for roughly10-15% of GDP for developed countries and can amount to as mush as 20% of GDP for developing countries (Kashap, 2004). The public sector spends between \$1.4 and \$1.6 trillion annually. In particular, the US federal government alone spent \$231.08 billion in 2000 while state and local governments spent about six times more than the federal government in the procurement process (Thai, 2001). In the state of Vermont, state government spent about 8% of its total spending in transportation projects.[1] Included in this budget approximately \$0.2 billion was spent on road construction alone.

Procurers typically provide descriptions of their unique needs including time delivery and payment conditions before letting auction and require contractors to comply the defined specifications to fit a certain level of quality specifications and price estimates. There is however often a discrepancy between the original contract and the final contract specifications and price estimates due to incomplete designs or unexpected changes. Such a discrepancy leads to extensive renegotiations between

[1]Source: usgovermentspending.com

two parties in the public sector.

Ex post changes to procurement contracts are common and costly for governments. In empirical reports, Bordat, McCullouch, and Sinha (2004) find that cost overruns are almost 9% of total contract amounts and 12% of all contracts experienced time delays in Indiana between 1995 and 2002. In addition, Oladapo (2007) reports that the changes in specifications and scope of a project account for 79% of the total cost overrun and 68% of the total time overrun in the Nigerian road construction industry. Oudot (2006) documents that 56% of contracts are renegotiated increasing the cost by 5% to 30% in French defense procurement sector while Guasch, Laffont, and Straub (2008) found that 53% of contracts in the transportation sector in Latin America were renegotiated and this percentage increases to 76% in water sector consisting of portable water, sewer and composite water.[2] Bourn (2001) reports that 55% of Public Finance Initiative (PFI) projects have experienced changes in United Kingdom.

Although renegotiations in public procurement frequently take place and their impacts on the economy are significant, only few empirical studies have been conducted in the literature. The objective of my dissertation is to study the impact of ex post renegotiations on a bidder's bidding behavior and markups. The potential renegotiations will change a bidder's ex post incentive mechanism and ex ante bidding strategy, often significantly raising the costs of public procurement. For example, when firms anticipate that procurement contracts are renegotiated after they are awarded, they incorporate these expectations into their ex ante bidding behavior. Renegotiations also create adaptation costs that relate to legal conflict and dispute costs. Therefore, the effect of ex post renegotiation on markups is dependent on the relative magnitude between those two factors. Further, this research studies the factors associated with the frequency and magnitude of renegotiations.

[2] They use nearly 307 concession contracts awarded between 1989 and 2000 in Latin America (Argentina, Brazil, Chile, Colombia, and Mexico).

Examinations of ex post renegotiation in procurement auction could lead to considerable benefits for the public by providing policy implications that mitigate cost overruns in road construction industry.

This dissertation consists of three essays that analyze ex post renegotiation in procurement auctions studying different components of renegotiation. In the first essay, we estimate the incidence and magnitude of strategic bidding. When firms bid in procurement auctions, they take into account the likelihood of future contract renegotiations. If they anticipate that certain input quantities will change ex post, they have an incentive to strategically skew their itemized bids, thereby increasing profits for themselves and costs for the procuring agency. We develop and estimate a structural model of strategic bidding using a dataset of road construction projects in Vermont. We find that firms engage in strategic bidding that increases profit margins by 3-4% at the project level, and 16-18% on the specific items that are renegotiated.

The second essay continues to study the impact of incomplete contracts on procurement costs in road construction auctions. Ex ante contracts in these auctions often fail to specify all of the potential construction contingencies, and consequently changes in scope are necessary after construction begins. Unlike quantity adjustments, every bidder typically has symmetric information on extra work adjustments because of project uncertainty. We find evidence that there is a statistically significant difference in costs of firms between auctions with and without extra work adjustments. Substantial adaptation costs are responsible for the higher procurement outlays in incomplete contracts. We also find that bidders inflate their bids to incorporate risk premiums in incomplete contracts; however, our estimates suggest that this bidding behavior does not affect their profit margins.

In the final essay, we examine the factors that contribute to contract renegotiation in Vermont through an empirical analysis of change orders. We find that firms' bidding behavior is capable of predicting change orders. In particular, greater disagreements in project valuation among bidders, and between the winning bidder and the state engineers, predicts a greater incidence of change orders. Moreover, we find evidence supporting the hypothesis that "top" firms, those with significant presence in the market, possess superior information about whether projects are likely to have change orders, bid accordingly and are more likely to renegotiate contracts. In such concentrated industries, top firms could use their power to sway renegotiation outcomes to their favor. However, conditional on submission, there is very little evidence that top firms' change orders are any more costly than those of other firms. Finally, we find that project characteristics associated with uncertainty and project complexity, such as size, duration and location are valuable predictors of contract renegotiations.

1.2 Literature on Procurement Auction with Renegotiation

This section briefly reviews literature on general procurement auctions and renegotiations in government contracts in particular.[3] In practice, the Federal Acquisition Regulation (FAR) favors the use of auction mechanism in the public sector because of its benefits such as high efficiency and low prices. Particularly, the use of competitive auction mechanism that leads to high competition and transparency is preferred.[4] However, the competitive awarding mechanism would not be efficient for complex projects with the expectation of ex post adaptations. In procurement

[3] McAfee and McMillan (1987) (p. 701) define that "An auction is a market institution with an explicit set of rules determining resource allocation and prices on the basis of bids from the market participants."

[4] There are four types of award mechanisms: open competitive bidding; invited bidder bidding; pre-qualified bidders bidding; negotiations. In general, competitive tendering auction includes the first three types.

award mechanisms, there is a trade-off between efficiency of cost minimization and ease of adaption of change orders (Bajari and Tadelis, 2006). The competitive bidding mechanism would fail to achieve efficiency due to the ex post adaptation costs. Further, regarding flexibility and renegotiation in the field, Chong, Staropoli, and Yvrande-Billon (2009) show that negotiation may be more efficient as an award mechanism in procurement when projects are complex or less potential competition is expected.

In payment structures, a fixed price contract has ex ante incentives on cost savings and may be less flexible for adopting ex post changes to the scope of work. Thus, a fixed price contract will be preferred if contracts are initially well specified and it is easy to detect the deviations from the original contract. Meanwhile, a cost plus contract provides flexibility in accommodating unforeseen changes while contractors have weak cost minimization incentives under a cost plus framework. In that case, a cost-plus contract is more feasible if ex post substantial changes are expected and adversarial renegotiation is anticipated in complex projects.[5] Bajari and Tadelis (2001) show that expected ex post adaptation costs are an important consideration in procurement contract selection. Bajari, Houghton, and Tadelis (2014) estimate the adaptation costs of \$2.7 per \$1 of expected contract adjustment in the procurement of highway construction projects in California. They emphasize that bidders inflate their bids to incorporate high risk premiums that result from the loss occurred from ex post adaptation costs.

Many local state governments provide a detailed project description including state engineer's cost estimates which reduce informational asymmetries among bidders (De Silva, Kosmopoulou, and Lamarche, 2009). It includes estimates of quantities and prices of each task in the project. The effect of sharing information on bidding behavior has been considered since the early theoretical paper by Milgrom

[5]See Bajari, McMillan, and Tadelis (2009) for more details.

and Weber (1982), which proves that releasing information causes rational bidders to shade their bids to offset the winner's curse in common value auction. Goeree and Offerman (2002) also show that releasing information helps bidders reduce uncertainty about the value of item and the winner's curse in their experimental setting. De Silva, Dunne, Kankanamge, and Kosmopoulou (2008) support this theory using data from road construction in Oklahoma and Texas. Furthermore, De Silva, Kosmopoulou, and Lamarche (2009) find that the release information will help new entrants survive longer in the construction market.

Contract theory underlines the importance of completely specifying a contract so that there is no strategic manipulation of bids in light of potential renegotiations. In practice, however, firms are more likely to strategically read the plans and specifications, and thereby they manipulate their bids in anticipation of ex post renegotiations. The plans and specifications described on the original contract may be altered in the field as a complex project often consists of a higher number of tasks. In reality, it is hard for the engineers to provide the complete design and specification for every construction contingency in the design stage. Firms know that the procurer cannot renegotiate the price of a task in a contract due to the FAR guidelines unless a completely new task is added to the contract in the field. As in Athey and Levin (2001), firms are able to increase their expected profits by submitting high unit prices on items that they expect to overrun in the future and by submitting lower unit prices on items whose actual quantity used is lower.

Contract theory predicts that there is no need to be renegotiated if the contract specifies all possible contingencies. In reality, it is hard to provide a complete contract for complex projects. In this case, renegotiations could be efficiency-enhancing unless they are abused. However, each party (more likely a contractor in procurement auction) uses the renegotiation to seek rents.[6] Once a contractor begins to

[6]The general explanation of incomplete contracts builds upon the existence of transaction costs associated with specifying all the contingencies for a complete contract. According to transaction

work, the procurer would have little bargaining power relative to the contractor since there is no alternative contractor to complete the project. When the procurer is faced with a hold-up problem (i.e. lower bargaining power) the contractor would utilize the renegotiations as an opportunity of a windfall transfer to him. Therefore, some literature considers renegotiation as the form of opportunism causing inefficiencies.[7] Iossa, Spagnolo, and Vellez (2007) argue that renegotiations can have negative effects on ex ante efficiency because of a bidder's weak incentive to reduce cost or to improve quality when the contractor expects future favor renegotiation. They argue that the expectation of renegotiation in the field also distorts bidder's bidding behavior in the auction letting. In particular, bidders have incentives to bid aggressively to maximize the probability of winning, and the winner calls for a renegotiation to change the original contract.

Wang (2000) includes a possibility of renegotiation in a theoretical model of sealed bid auction. He shows that the likelihood of renegotiation will be low as long as either cost of renegotiation or the number of bidders increases. He presents that the social welfare with renegotiation could be lower than that without renegotiation if the procurer does not have full bargaining power in the renegotiation. As more bidders participate in auction, the bids are uniformly closer to the actual cost and the possibility of renegotiation is low in the procurement auction. Oudot (2006) identifies uncertainty as one of the main determinants of renegotiations in French defense procurement contracts. In the study, the sources of the uncertainty are specific to the defense sector such as contractual uncertainty or technological uncertainty.

---

cost theory, incomplete contracts occur mostly because of the presence of transaction costs. Hart and Holmstrom (1987) identify the sources of transactions costs: (1) the cost of foreseeing the various contingencies that may occur; (2) the cost of making an agreement to deal with such contingencies; (3) the cost of writing the complete contract; (4) the cost of legal enforcement.

[7] Williamson (1985) means that "opportunism refers to the incomplete or distorted disclosure of information, especially to calculated efforts to mislead, distort, disguise, obfuscate, or otherwise confuse" (p. 47).

In the road construction industry, renegotiation can occur with price adjustments due to input price changes. Bidders are exposed to the risk of unanticipated changes in cost of major inputs such as fuel (gas and diesel), asphalt (cement) or steel. Therefore, it is apparent that rational bidders inflate their bids to reduce risk exposure in a long-term contract. This bidder's bidding strategy eventually causes the increases in the payments paid by the public sector. Thus, a number of states introduce a price adjustment clause as one type of renegotiations on the contract to relieve contractors of extreme volatility of the input prices (for a more discussion of this, see Kosmopoulou and Zhou (2014)).

Guasch (2004) examines around 1,000 concession contracts in Latin America during 1990s. The study finds that competitive bidding, price-cap regulation, contracts with investment requirements, absence of a regulatory agency at the work site, macroeconomic shocks, and political cycles will affect the incidence of renegotiations. Contractors initiated 57% of renegotiations while the government initiated only 27% of renegotiations in the transportation sector during the sample periods. Hsieh, Lu, and Wu (2004) investigate 90 metropolitan public work projects in Taiwan. Being consistent with the literature, this study also finds that the most change orders result from incomplete planning and designs. The renegotiation amounts account for 10-17% variations of total project costs in the public works. Bordat, McCullouch, and Sinha (2004) demonstrate that the proportion of the difference between the winning and second bid has positive effect on the frequency of change orders. They also find that the larger the contract size, the more likely the project experiences time delays in completion.

An extensive empirical literature recently focuses more on structural models of equilibrium bidding, which assume that the observed bids are the outcomes of the Bayesian-Nash equilibrium.[8] The goal of this approach in empirical work on auc-

[8] Hendricks and Paarsch (1995), Athey and Haile (2007), and Hendricks and Porter (2007) provide extensive surveys of the structural analysis. In particular, Athey and Haile (2007) highlight

tions is to recover the underlying distribution of bidder's valuations from auction data. The estimation procedures require econometricians to find the joint distribution of private signals from observed bids. In general, there are two ways to estimate the distribution: parametric or nonparametric approaches. Although nonparametric analysis is more flexible, economists often have to make functional form assumptions on the distribution of bidder valuations to identify the structural parameters due to complex theoretical model or limited data availability. Donald and Paarsch (1993) develop the parametric structural estimation and propose maximum likelihood methods for estimating the distributions. Bajari and Hortacsu (2003) study eBay coin auctions with endogenous entry and they estimate parametric auction models by specifying likelihood function. On the other hand, Guerre, Perrigne, and Vuong (2000) propose a two step procedure for nonparametrically estimating distribution of bidders' private values from observed bids in a symmetric independent private value framework.

Hendricks, Pinkse, and Porter (2003) and Haile, Hong, and Shum (2006)have developed methods to distinguish the values between private and common value components by formulating nonparametric tests.[9] The distinction between values is important in policy aspects. For example, if common component is the main determinant of bids, high competition does not guarantee lower procurement costs while lower procurement costs could be achieved in competitive market with private value environments. Li, Perrigne, and Vuong (2002) and Campo, Perrigne, and Vuong (2003) extend nonparametric estimation by allowing bidder asymmetry with affiliated private values which is an intermediate case between private and common value auction.

nonparametric estimation which we employ in our essays.

[9] If each bidder knows its own valuation and no bidder knows with certainty other bidders' values of the object, such a specification is called private value model. In a common value environment, the object has an identical value for all bidders and the valuation is unknown at the bidding.

Other empirical auction literature focuses on multidimensional attributes in procurement auction. Che (1993) and Lewis and Bajari (2011) analyze scoring auction mechanism that includes quality and completion time in the awarding process, respectively. Marion (2007) and Krasnokutskaya and Seim (2011) consider the effect of bid preference programs for small businesses on the overall cost of procurement in California. In a related study of the policy effect, De Silva, Dunne, Kosmopoulou, and Lamarche (2012) analyze the effect of subcontracting goals on bidding behaviors and procurement costs in Texas. De Silva, Dunne, and Kosmopoulou (2003) investigate the bidding behaviors of entrants and incumbents and find entrants bid more aggressively. Lewis and Bajari (2014) examine how incentive contracts affect contractors' work rate and completion days taken, and then find evidence of ex-post moral hazard in highway procurement.

In the nonparametric structural estimation, we estimate the latent cost distributions of bidders by controlling for bidder, auction characteristics and factors affecting the economic environment. In the count model analysis we take into account the possibility of endogeneity of top firms in the market. The rest of the dissertation is organized as follows. Chapter 2 presents the first essay, "Strategic Bidding and Contract Renegotiation." Chapter 3 includes the second essay, "Renegotiation on Incomplete Procurement Contracts." The third essay, "Uncertainty and Contract Renegotiation in Public Procurement", is presented in Chapter 4. The last chapter offers concluding remarks.

Chapter 2

Strategic Bidding and Contract Renegotiation[1]

2.1 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. government's procurement guidelines, the Federal Acquisition Regulation (FAR), 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

[1] This chapter is based on a working paper coauthored with Georgia Kosmopoulou, Carlos Lamarche and Richard Sicotte.

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 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 2.2 provides an overview of the data. In Section 2.3, we present the model and our identification strategy and discuss structural empirical analysis. Section 2.4 offers concluding remarks.

2.2 Data and summary statistics

2.2.1 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.[2] 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.[3] The engineer's plans provide a list of quantities for each item in the project plan. All participants in the auctions are required to submit bids for each item 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*

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

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

Table 2.1: 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	-$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.

upon all of the following: .1 The change in the Work; .2 The amount of the adjustment, if any, in the Contract Sum; and .3 The extent of the adjustment, if any, in the Contract Time."

Change orders are widely used in fixed-price contracts and are filled only if changes of plans or specifications are significant relative to the original contracts.[4] They include ex post payments made by positive quantity, 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.

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

Table 2.1 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 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 of items per contract is 60.

Figure 2.1 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 differ-

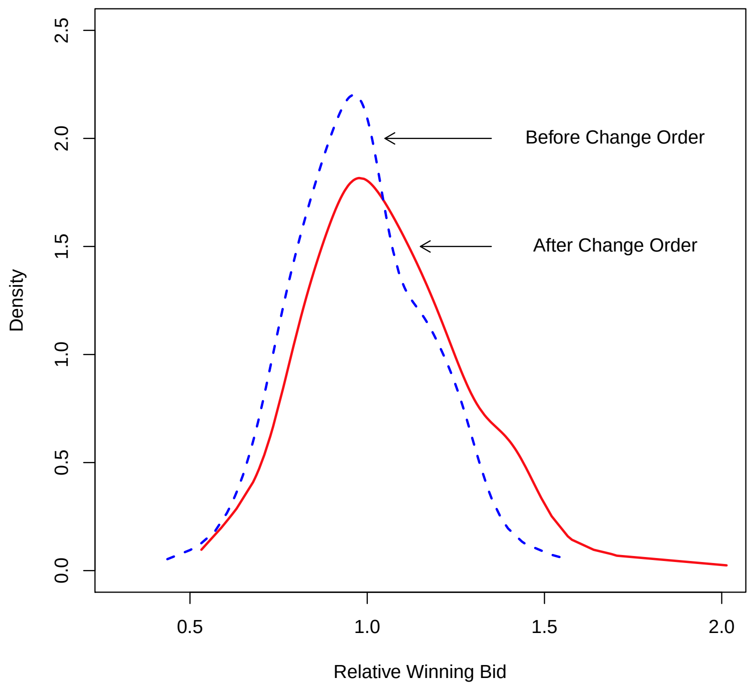


Figure 2.1: Kernel Density Plot of Relative Winning Bids

ent challenges for the transportation agencies. Price adjustments are based on a market index that is independent of firms' reported bids.[5] They are triggered by fluctuations in the price of oil caused by economic uncertainty. 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. 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.

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

2.2.2 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:

$$y_{iat} = \mathbf{X}'_{at}\boldsymbol{\beta} + \mathbf{W}'_{it}\boldsymbol{\gamma} + \mathbf{Z}'_{t}\boldsymbol{\delta} + m_t + \alpha_i + u_{iat}, \tag{2.1}$$

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.[6] We also use the "project type" dummy to control for bidding behavior across different types of projects.

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

We include a number of variables to control for bidder and rival characteristics. Consistent with prior literature, we construct each bidder's and rival's distance to work sites and their backlogs. We also include detailed financial information on each bidder such as assets, debt and revenue.[7] The information allows us to measure business strength and capacity more accurately, rather than resorting to local workloads as a proxy of firm activity based on state-level data.[8] 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.[9] To control for the possibility of systematic differences in the behavior of top firms and fringe firms facing financial constraints, we interact the debt to asset ratio with a variable indicating whether a bidder is a top firm. In addition, we also allow for differential bidding behavior in local markets by incorporating a measure of a bidder's local market power as an account of a firm's market share. A firm's local market power is defined by its working history at a county level. It is the proportion of all outstanding

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

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

[9]The 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 (2014).

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 2.3. In Table 2.2, 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.[10] 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 those, 498 items never appear on a change order.

Results from this estimation are displayed in Table 2.2. 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

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

Table 2.2: 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)
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.

Continued

Independent Variable	Project Bids					Itemized Bids
	Full Sample			Subsample		Full Sample
	(1)	(2)	(3)	(4)	(5)	(6)
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 Permits	-0.003	-0.003				-0.009
	(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.

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 (2.1). 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 (2.1) 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 (2.1) generating estimates of the latent cost distributions for projects with or without renegotiations.

Lastly, the analysis in the third column of Table 2.2 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 2.3 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 might be interpreted as evidence suggesting that 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 2.3 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.[11] For instance, the task associated with Superpave Bituminous Concrete Pavement, or item 490.30, has roughly 1/3 chances of being renegotiated, while work on installing Galvanized Steel Beam Guardrail, or item 631.17, has not been renegotiated despite 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 the 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 2.3.1.

[11] The pay item description for the items presented in Table 2.3 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).

Table 2.3: 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. The last 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 2.3.

2.3 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.

2.3.1 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 $H_j(s^i) \equiv \text{pr}(\mathbf{b}^i \cdot \mathbf{q}^e > \mathbf{b}^j \cdot \mathbf{q}^e)$. Finally, $\prod_{j \neq i}(1 - H_j(s^i))$ is defined as the probability that bidder i wins the auction with s^i.

Unlike Bajari, Houghton, and Tadelis (2014) who assume bidders have 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:

$$
\begin{aligned}
&\pi^i(\mathbf{b}^i, \mathbf{c}^i, \mathbf{k}) \\
&= \left[\mathbf{b}^i \cdot (\mathbf{k} \cdot \mathbf{q}^a + (\mathbf{1} - \mathbf{k}) \cdot \mathbf{q}^e) - \mathbf{c}^i \cdot (\mathbf{k} \cdot \mathbf{q}_t^a + (\mathbf{1} - \mathbf{k}) \cdot \mathbf{q}^e)\right] \times \left[\text{pr}\left(\mathbf{b}^i \cdot \mathbf{q}^e < \mathbf{b}^j \cdot \mathbf{q}^e\right)\right] \\
&= \left[\mathbf{b}^i \cdot (\mathbf{k} \cdot \mathbf{q}^a + (\mathbf{1} - \mathbf{k}) \cdot \mathbf{q}^e) - \mathbf{c}^i \cdot (\mathbf{k} \cdot \mathbf{q}_t^a + (\mathbf{1} - \mathbf{k}) \cdot \mathbf{q}^e)\right] \times \left[\prod_{j \neq i}(1 - H_j(s^i))\right], \qquad (2.2)
\end{aligned}
$$

where the vector $\mathbf{1}$ 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:

$$\frac{\partial \pi^i(\mathbf{b}^i, \mathbf{c}^i, \mathbf{k})}{\partial b_t^i} = (\mathbf{k}\cdot\mathbf{q}^a + (\mathbf{1}-\mathbf{k})\cdot\mathbf{q}^e)\left[\prod_{j\neq i}(1-H_j(s^i))\right] - \big[\mathbf{b}^i\cdot(\mathbf{k}\cdot\mathbf{q}^a + (\mathbf{1}-\mathbf{k})\cdot\mathbf{q}^e) \\ -\mathbf{c}^i\cdot(\mathbf{k}\cdot\mathbf{q}^a + (\mathbf{1}-\mathbf{k})\cdot\mathbf{q}^e)\big] \times \left[q_t^e \sum_{k\neq i} h_k(s^i) \prod_{j\neq i,k}(1-H_j(s^i))\right] = 0. \quad (2.3)$$

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

$$(\mathbf{b}^i - \mathbf{c}^i)\cdot(\mathbf{k}\cdot\mathbf{q}^a + (\mathbf{1}-\mathbf{k})\cdot\mathbf{q}^e) = \left(\frac{k_t q_t^a + (1-k_t)q_t^e}{q_t^e}\right) \times \left(\sum_{j\neq i}\frac{h_j(s^i)}{(1-H_j(s^i))}\right)^{-1}. \quad (2.4)$$

Equation (2.4) 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 (2.4) can be written as follows:

$$(\mathbf{b}^i - \mathbf{c}^i)\cdot\mathbf{q}^e = \left(\sum_{j\neq i}\frac{h_j(s^i)}{(1-H_j(s^i))}\right)^{-1}. \quad (2.5)$$

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

$$(\mathbf{b}^i - \mathbf{c}^i)\cdot\tilde{\mathbf{q}}^a = \left(\frac{k_t q_t^a + (1-k_t)q_t^e}{q_t^e}\right)\left(\sum_{j\neq i}\frac{h_j(s^i)}{(1-H_j(s^i))}\right)^{-1} \quad (2.6)$$

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.

2.3.2 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,

$$y_{rj}^{(m_r)} \equiv \mathbf{b}_{rj}^{(m_r)} \cdot \mathbf{q}^{e(m_r)} = \boldsymbol{\mu}_r' \mathbf{x}_{rj}^{(m_r)} + \boldsymbol{\theta}_r' \mathbf{z}^{(m_r)} + \varepsilon_{rj}^{(m_r)}, \tag{2.7}$$

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.[12,13]

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 (2.7) 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:

$$H_{rj}^{(m_r)}(b) = Pr\left(\boldsymbol{\mu}_r' \mathbf{x}_{rj}^{(m_r)} + \boldsymbol{\theta}_r' \mathbf{z}^{(m_r)} + \varepsilon_{rj}^{(m_r)} \leq s_r^i\right) \equiv G\left(b_{rj}^{(m_r)}\right), \tag{2.8}$$

[12] 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 2.6, and therefore, we offer results based on a more parsimonious model (2.7). This specification include variables that are similar to the ones employed in Bajari, Houghton, and Tadelis (2014).

[13] The results from estimating equation (2.7) were similar to the results presented in Table 2.2'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.

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 (2.7) 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.[14] 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.

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 $\mathbf{c}_1^i$,

$$(\mathbf{b}_0^i - \mathbf{c}_0^i) \cdot \mathbf{q}^e = \left(\sum_{j \neq i} \frac{\hat{h}_{0j}(s^i)}{(1 - \hat{H}_{0j}(s^i))} \right)^{-1} \tag{2.9}$$

$$(\mathbf{b}_1^i - \mathbf{c}_1^i) \cdot \hat{\mathbf{q}}^a = \left(\frac{\hat{k}_t q_t^a + (1 - \hat{k}_t) q_t^e}{q_t^e} \right) \left(\sum_{j \neq i} \frac{\hat{h}_{1j}(s^i)}{(1 - \hat{H}_{1j}(s^i))} \right)^{-1} \tag{2.10}$$

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 2.3, 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

[14] It is interesting to observe that the parametrization of the model used in equation (2.7) 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 (2.7) (e.g., the median markup for projects with and without negotiations were quantitatively and qualitatively similar to the ones reported below in Table 2.6).

the solution of equations (2.9) and (2.10) 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.

2.3.3 Data

The estimation of equations (2.9) and (2.10) 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 (2.9) and (2.10) 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 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.

Table 2.4: 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.

The descriptive statistics for these three groups are presented in Table 2.4. We restrict attention to projects with an estimated cost between $200,000 and $5 million, roughly excluding the largest and smallest 10% of road/highway projects to achieve greater homogeneity across groups. As shown by the table, the more complex a project is, the more likely it will be renegotiated. This essentially implies that long and more complex projects are renegotiated with higher frequency. The issue of auction heterogeneity is known to affect the quality of statistical inferences and consequently it is addressed by the estimation procedure described in the previous sections which follows closely Guerre, Perrigne, and Vuong (2000), Haile, Hong, and Shum (2006), and Bajari, Houghton, and Tadelis (2014).

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 2.5, and focus on their cost estimates or their markups at the itemized level.[15] 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 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.

[15] 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.

Table 2.5: Comparison of Summary Statistics for Pay Items

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

Standard errors are in parentheses.

2.3.4 Estimation results for project costs and markups

Figure 2.2 shows the estimated relative project cost distributions for projects with and without renegotiations.[16] 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 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

[16] These figures are obtained by using subsets $\mathcal{S}_A$ (left panel) and $\mathcal{S}_B$ (right panel).

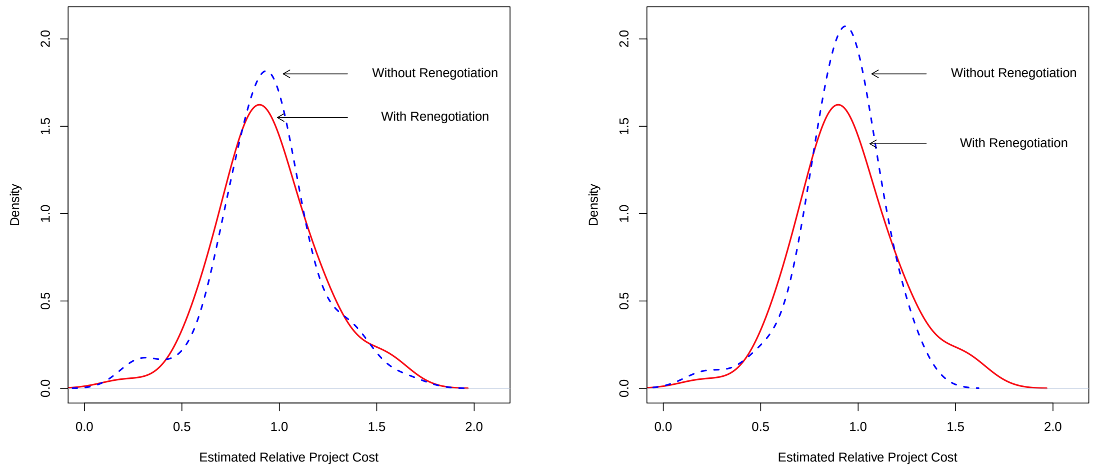


Figure 2.2: Relative cost in projects with and without renegotiation

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 2.6, we summarize our estimates of bidders' markups over estimated costs for projects with and without positive quantity renegotiations after controlling for unobserved heterogeneity.[17] We report results between 0.2 and 0.8 quantiles of the distributions to avoid interpreting results from potentially biased estimates at the tails. We find that bidders achieve higher markups in projects when renegotiation is anticipated. Furthermore, the estimated median markups are similar to those reported in Bajari, Houghton, and Tadelis (2014). The estimated median markups are 8.70% 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

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

Table 2.6: Markups for projects with and without renegotiation

Group	Percentile						
	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

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 2.6 suggests a difference of 3-4% at the median level between markups in contracts with and without renegotiation.

2.3.5 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 2.5 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 (2.5) for projects with $k_t = 0 \ \forall t$ as,

$$\mathbf{c}_0^i \cdot \mathbf{q}_0^e = \mathbf{b}_0^i \cdot \mathbf{q}_0^e - \left(\sum_{j \neq i} \frac{h_{0,j}(s_0^i)}{(1 - H_{0,j}(s_0^i))} \right)^{-1}. \tag{2.11}$$

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

$$\sum_{t=m+1}^{T}(b_{0,t}^{i} - c_{0,t}^{i})q_{0,t}^{e} = \sum_{t=1}^{m} c_{0,t}^{i}q_{0,t}^{e} - \sum_{t=1}^{m} b_{0,t}^{i}q_{0,t}^{e} + \left(\sum_{j\neq i}\frac{h_{0,j}(s_0^i)}{(1 - H_{0,j}(s_0^i))}\right)^{-1}, \tag{2.12}$$

where the left hand side of equation (2.12) denotes tasks that are not renegotiated in other projects that can include renegotiated items. Moreover, equation (2.6) is equivalent to,

$$\left[\sum_{t=1}^{m}(b_{1,t}^{i} - c_{1,t}^{i})\tilde{q}_{1,t}^{a} + \sum_{t=m+1}^{T}(b_{1,t}^{i} - c_{1,t}^{i})q_{1,t}^{e}\right] = \left(\frac{k_t q_t^a + (1-k_t)q_t^e}{q_t^e}\right)\left(\sum_{j\neq i}\frac{h_{1,j}(s^i)}{(1 - H_{1,j}(s^i))}\right)^{-1}. \tag{2.13}$$

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

$$\sum_{t=m+1}^{T}(b_{0,t}^{i} - c_{0,t}^{i})q_{0,t}^{e} = \sum_{t=m+1}^{T}(b_{1,t}^{i} - c_{1,t}^{i})q_{1,t}^{e}, \tag{2.14}$$

suggesting that we can substitute equation (2.12) in the second term on the left hand side of equation (2.13). After some algebra, it is possible to evaluate the total cost distribution for the group of renegotiated items as follows,

$$\begin{aligned}\sum_{t=1}^{m} c_{1,t}^{i}\tilde{q}_{1,t}^{a} = \sum_{t=1}^{m} b_{1,t}^{i}\tilde{q}_{1,t}^{a} + \left[\left(\sum_{j\neq i}\frac{h_{0,j}(s_0^i)}{(1 - H_{0,j}(s_0^i))}\right)^{-1} - \sum_{t=1}^{m} b_{0,t}^{i}q_{0,t}^{e} + \sum_{t=1}^{m} c_{0,t}^{i}q_{0,t}^{e}\right] \\ - \left[\left(\frac{k_t q_{1,t}^a + (1-k_t)q_{1,t}^e}{q_{1,t}^e}\right)\left(\sum_{j\neq i}\frac{h_{1,j}(s_1^i)}{(1 - H_{1,j}(s_1^i))}\right)^{-1}\right].\end{aligned} \tag{2.15}$$

To uncover the cost of renegotiated items, $(c_{1,1}, \ldots, c_{1,m})$, we first estimate the left hand side of equation (2.11) and then we use these estimates to obtain the left hand side of equation (2.15). Using the procedure introduced in Section 2.2, we can similarly obtain $\hat{h}_{0,j}$, $\hat{h}_{1,j}$, $\hat{H}_{0,j}$, $\hat{H}_{1,j}$, $\hat{k}_t$, and $\hat{q}^a_t$. In order to estimate $(c_{0,1}, \ldots, c_{0,m})$, we first obtain $\hat{\mathbf{c}}_0$ from equation (2.11) and then obtain, $\hat{c}^i_{0,t} = b^i_{0,t} q^e_{0,t} \hat{\mathbf{c}}_0 / s^i_0$ for $t = 1, \ldots, m$. 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 2.3. 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 2.5 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 $c^i_{1,t}$ after we estimate equation (2.15) 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 2.3 shows that there are significant cost differences between a set of items when they are renegotiated and when they are not renegotiated.[18] 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

[18]These figures are obtained by using subsets $\mathcal{I}_A$ (left panel) and $\mathcal{I}_B$ (right panel). Unit costs are expressed in dollars.

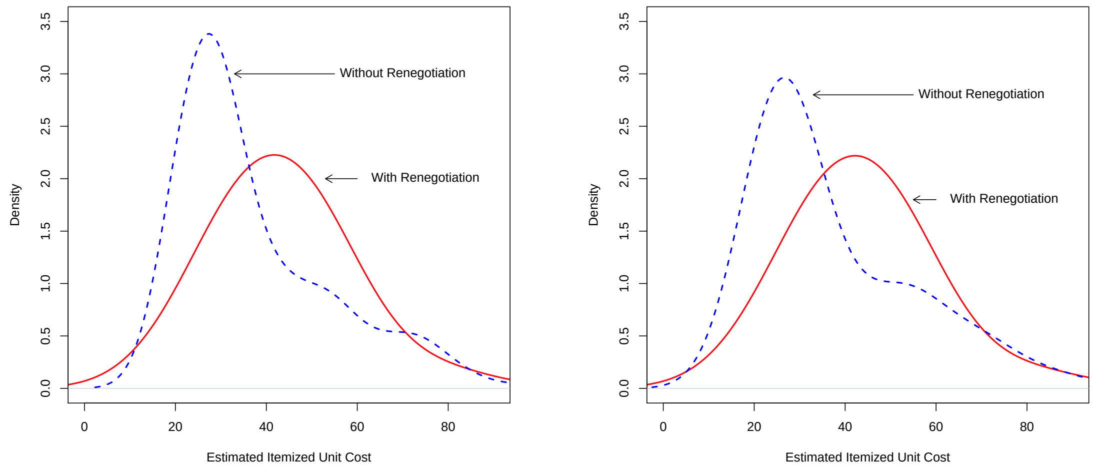


Figure 2.3: Itemized Unit Cost distribution for items with and without renegotiation

similar and are not sensitive to employing either subsample $\mathcal{I}_A$ or $\mathcal{I}_B$.

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 2.7 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

Table 2.7: Markups for items with and without renegotiation

Group	Percentile						
	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

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 2.7 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 2.7. We are able to estimate the markups for items that are not renegotiated in contracts that have renegotiated items.[19] 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

[19] 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 2.4. The bottom part of Table 2.7 presents results based on the subset $\mathcal{I}'_B$, which consists of items from projects with no renegotiation or added/dropped items.

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 2.7 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 2.7, 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.

2.3.6 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 2.8). 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 2.8, 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 2.3 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

Table 2.8: 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.

proportion of the total project costs, explaining in part the seemingly conflicting finding at the project and item levels.

2.3.7 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 2.4 reports the results of the exercise demonstrating how the cost distribution shifts when the probability of renegotiation changes marginally.[20] 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 item-

[20]These figures are obtained by using subsets $\mathcal{I}_A$ (left) and $\mathcal{I}_B$ (right). Unit costs are expressed in dollars.

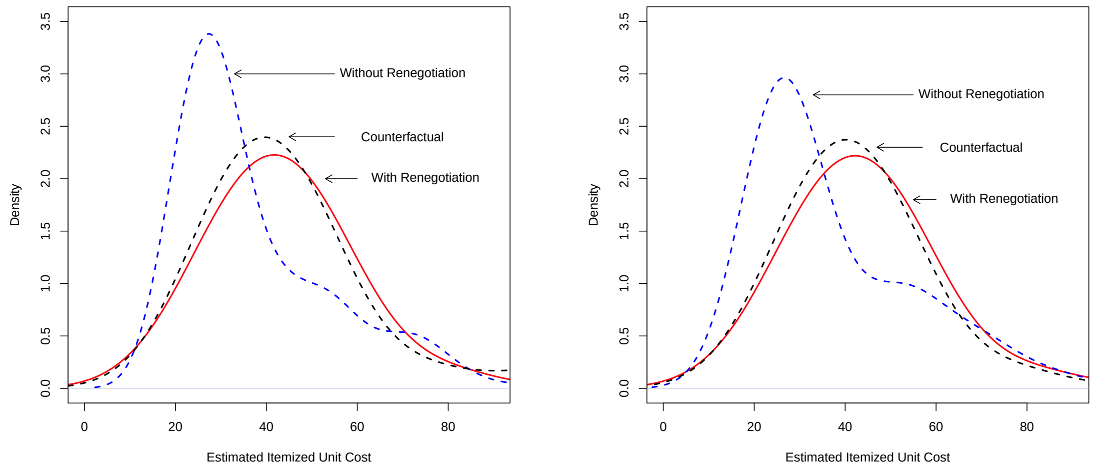


Figure 2.4: Counterfactual estimations for itemized costs

Table 2.9: 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%

ized cost using the new probability. We incorporate the adjusted itemized bids to estimate, from equation (2.15), 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 2.9). 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%.

2.4 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.

Chapter 3

Renegotiation on Incomplete Procurement Contracts

3.1 Introduction

Contract theory states that renegotiation is desirable for incomplete contracts and occasionally unavoidable for contracts that face exogenous project uncertainty.[1] However, contract renegotiations are often costly and it can be difficult to reach an efficient agreement. Highway construction contracts are commonly exposed to ex post cost adjustments through change orders, which are used to extend the duration and scope of contracts. Ex post adjustments through change orders occur for specific reasons and payments depend on the type of adjustments. Fuel price adjustments are triggered based on a market price index and the reimbursement is independent of the bid.[2] Quantity adjustments could be associated with engineering errors and adjustment amounts are determined by the bid the contractor

[1] Bajari and Tadelis (2006) claim that renegotiation could achieve ex post contract efficiency in complex projects, which are defined as projects in which very high costs are necessary to provide complete contingencies.

[2] Fuel price adjustment amount generally 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 clause.

submitted at the auction stage. In contrast, an extra work adjustment is associated with incomplete contracts due to project uncertainty of unexpected fundamental change in scope. The price of the compensation for this extra work is determined by a new agreement between two parties.[3] This unique compensation process could cause significant adaptation costs at the renegotiation stage.

Starting with a seminal paper by Grossman and Hart (1986), there is a rich theoretical literature on incomplete contracts. This literature considers contracts to be often incomplete because of bounded rationality and contractual transaction costs of writing an ex ante complete contract which describes a set of every possible contingency.[4] Hart and Moore (1988) show that the possibility of ex post renegotiation on ex ante incomplete contracts will not lead to the socially optimal investment level. Segal (1999) explores how the uncertainty or complexity of the ex post environment could cause the contract to be incomplete. There is also a wide body of empirical literature focusing on the determinants of contractual form as affected by contractual completeness (see Leffler, Rucker, and Mann (2008), Bajari, McMillan, and Tadelis (2009) and Chong, Staropoli, and Yvrande-Billon (2009)). These papers show that contractual incompleteness resulting from project complexity often affects the choice of optimal award mechanism. Recently, Bajari, Houghton, and Tadelis (2014) find that contractors increase procurement costs by skewing their bids on incomplete contracts.[5]

[3]The *Standard Specifications for Construction* book (Division 100, 1-9) in the Vermont Agency of Transportation defines the extra work as follows: "An item of work not provided for in the Contract as awarded but determined by the Engineer to be essential to the satisfactory completion of the Contract. Extra Work shall be performed at agreed upon prices or on a force account basis as provided in the Contract."

[4]Literature has considered that the ex ante indescribability leads to contractual incompleteness. In contrast, Maskin and Tirole (1999) argue that indescribability does not matter to achieve same expected payoffs as with fully contingent contract as long as there are risk averse agents who are able to probabilistically forecast their future payoffs. Hart and Moore (1999) argue that, even if contingencies can be perfectly described ex ante, the parties are unable to achieve first-best outcome in the real world because of lack of commitment not to renegotiate.

[5]Athey and Levin (2001) also analyze bid skewing in timber auctions and show that contractors are able to increase their expected profits by strategically skewing bidding in anticipation of ex post quantity changes.

In this paper, we examine direct effects of contractual incompleteness through contracts that require upon completion extra originally unspecified work. We estimate the distributions of latent costs and bidder markups using a structural analysis by employing a homogeneous set of contracts. Bajari, Houghton, and Tadelis (2014) show that ex post renegotiations induce not only adaptation costs but also large surpluses to contractors due to their strategic bidding behaviors.[6] We confirm that this cost increase is consistent and robust, even when we focus on only the contracts with extra work adjustments. There is a significant cost difference between projects that are renegotiated for extra work and projects that are not renegotiated. However, we find that renegotiations for unforseen components have no effects on bidder's profit margin, even when using detailed cost controls in our bid function estimations. Furthermore, we find no evidence that bidders strategically manipulate their bids in projects with ex post extra work adjustment, while Chapter 3 present strong evidence that firms strategically alter their bids and markups when they anticipate positive quantity adjustments in road construction industry.[7] Our differences can be attributed to the lack of asymmetric information in extra work. More informed bidders have strong incentives to strategically manipulate their bids to increase markups. However, in the case of projects with extra work, bidders typically have symmetric information regarding unforseen work.

This study is complementary to Bajari, Houghton, and Tadelis (2014), while we differ from the prior research in two ways. First, we examine the impact of

[6]It is commonly known that renegotiations are necessary to mitigate inefficiency caused by the incomplete contracts while each party (more likely a contractor in procurement auction) uses the ex post renegotiation to seek rents. Once contracts are awarded, the procurer would be locked in to the contract with little bargaining power. When the procurer is faced with hold-up problem (i.e. lower bargaining power) the contractor would utilize the renegotiations as the form of opportunism causing inefficiency. See Schmitz (2001) for a literature survey.

[7]Williamson (1976) points out that opportunistic renegotiation can happen at three different stages of the following; at the awarding of contracts, at the execution of contracts and at the reattribution of contracts. There is a vast empirical literature that investigates the opportunism at the bidding stage in public procurement. See, for instance, Guasch, Laffont, and Straub (2008) and Bajari, Houghton, and Tadelis (2014).

extra work, that can not be fully accounted for in the original contract, on bidder's behaviors and contract costs. In contrast, Bajari, Houghton, and Tadelis (2014) examines the effect of any type of ex post adjustments on the behavior of firms or the procurement costs. Hence, it is difficult to isolate the influence of incomplete contracts from simultaneous effects that result from multiple concurrent adjustments. A second difference lies in the empirical analysis, relaxing the assumption that bidders possess perfect foresight about ex post renegotiations which is employed in the previous literature (e.g, Bajari, Houghton, and Tadelis (2014) and Athey and Levin (2001)). Instead our model assumes that bidders forecast the likelihood and magnitude of extra work adjustments for each individual contract. In the empirical analysis, we estimate these likelihoods with a probability model, and incorporate the estimates into our structural analysis.

It is worth noting that unlike quantity adjustment, existing items on the original contract are not renegotiated in an extra work adjustment, but completely new items are added to the contract. Under the Federal Acquisition Regulation (FAR), bidders know that the procurer cannot renegotiate the price of an item in a contract, except in the case of an item added to the contract after a project is awarded. Hence, there is an incentive for contractors to act opportunistically in exploiting additional surplus when formulating the compensation for extra work with the procurers. There may be substantial extra costs for contracts due to ex post haggling and litigation over the payment agreements. Contract theory also asserts that renegotiation imposes various transaction costs, including adaptation costs. Therefore, the contractual incompleteness adds not only direct costs for executing new work, but also indirect costs associated with adaptation costs. Bajari, Houghton, and Tadelis (2014) estimate the adaptation costs of 70 cents to almost \$3 per \$1 of expected contract adjustment in the highway procurement industry in California.[8]

[8] Bajari, Houghton, and Tadelis (2014) defines adaptation costs as "...any costs that are incurred above and beyond the direct production costs of the project."

This paper proceeds as follows. The next section provides an overview of the data. Section 3.3 presents the model and structural empirical analysis. Section 3.4 offers concluding remarks.

3.2 Data and summary statistics

The data employed in this analysis contain information on road construction projects procured by the Vermont Agency of Transportation (VTrans) from May 2004 through December 2009. These projects include asphalt projects, bridge projects, traffic signal projects, as well as miscellaneous projects such as parking lots and landscaping. These auctions take place on a weekly basis in a sealed-bid format where the lowest bidder is awarded the contract for the price he or she bids. In overall procurement costs, VTrans spent around six billion dollars during our sample periods with the mean value of one billion dollars on these contracts every year. Most projects have an advertising period of 23 days with 16, 30, and 37 being typical variations. For each project VTrans provides detailed information, including engineer cost estimates, the location of the project, estimates of the number of days to complete the project and brief descriptions of the project. The engineer cost estimate provides overall cost projections and a list of components in the projet including brief descriptions, estimated quantities and required materials for all items.

In Vermont, any firm could become a plan-holder by purchasing the plans for a project, but only pre-qualified firms are able to bid on the project. The pre-qualification status determines the value of the projects and number of contracts a firm can undertake at the same time. Construction firms in the state are required to submit a certified financial statement and are assigned to a certain level of qualification based on their available working capital and performance histories. After the contract is awarded, the identity and the bids of all bidders are made publicly avail-

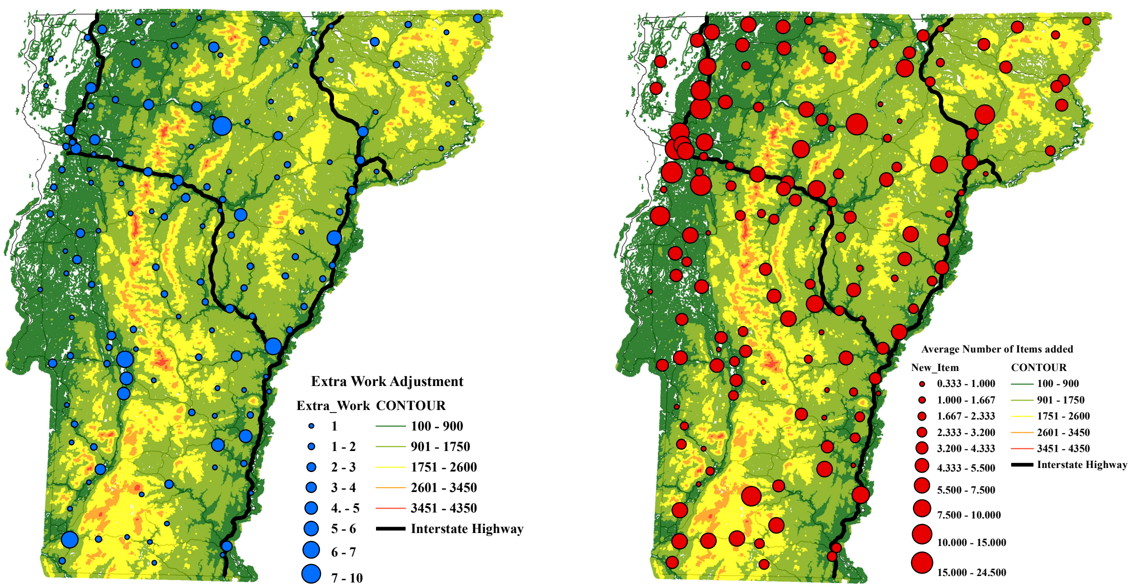


Figure 3.1: Project with Extra Work Location and Average Number of Items added in the Vermont Transportation Construction Industry

able. Therefore, we have information on the bids of all bidders and the identities of the potential, actual bidders and the winner for each project.

We also employ a change orders dataset, which includes ex post changed quantity and payment for each renegotiated item with a brief description of that change. There are five categories of adjustments to modify original contracts: fuel price adjustment, positive quantity adjustment, negative quantity adjustment, extra work adjustment and dropped item adjustment. We have information on any type of ex post payment paid by VTrans, including the extra work adjustments this study focuses on. A change order written as an amendment to the contract is widely used in a fixed-price contract to adjust compensation for the ex post changes.[9] Change orders are recorded if the changes are significant from the original contract in the Vermont transportation industry. VTrans is required to record the change orders only if the cost ex post is greater than or equal to 105% of the estimate values.

[9]Addenda is another type of contract amendment for changes to the plans and specifications. The difference from change orders is that addenda are issued before opening bids, hence bidders have sufficient time to incorporate the changes into their bid.

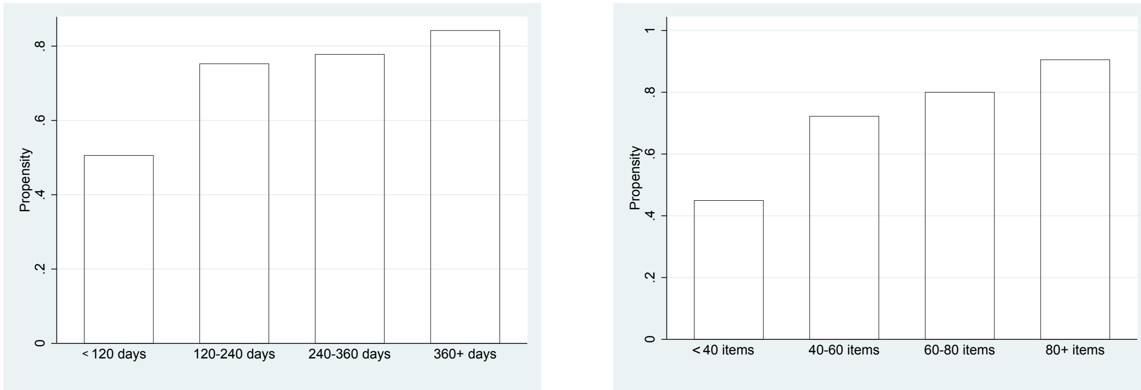


Figure 3.2: Propensity to experience extra work adjustments

Hence, we have full information on the actual quantity used of each task, changes in scope of the project and the final price paid on a contract.

Figure 3.1 illustrates that unknown site conditions lead to drastic changes on the contracts. The left panel shows the geographic distribution of the projects with extra work adjustments. There is substantial regional variation in the number of projects with the adjustment. The numbers of projects with extra work adjustments are especially high near mountains, where engineers could face more project uncertainty at the design stage. The more items are added to the original contract, the more incomplete the contract. The right panel shows that more items on average were added to projects with high elevation.

The possibility that the occurrence of extra work adjustments could be correlated with uncertainty is also supported by the relationship between estimates of working days or number of items of contracts and propensity of extra work adjustments. In Figure 3.2, the probability that projects experience extra work adjustments is approximately 84% when their estimates of the working days to complete contracts are greater than around 1 year. Furthermore, the propensity is about 90% when the number of project components is greater than 80 items in projects. The more the number of tasks in contracts, the higher is the probability of the occurrence of

Table 3.1: Descriptive Statistics

Variable	Number of Observations	Mean	Standard Deviation	Min	Max
Relative Winning Bid	312	0.968	0.191	0.436	1.762
Final Payment/Engineer Cost Estimate	312	1.025	0.223	0.532	2.014
Adjustment Amount ($)	312	114,566	219,474	-116,848	1,492,298
Extra Work Amount ($)	312	105,713	271,635	0	2,688,537
Adjustment/Engineer Cost Estimate	312	0.057	0.091	-0.174	0.770
Extra Work/Engineer Cost Estimate	312	0.058	0.118	0.000	0.876
Number of Bidders	312	3.349	1.959	1	11
Number of Items	312	60.228	35.346	2	245
Calendar Days	312	262.455	200.505	14	1221
Average Number of Extra Work	312	3.978	5.926	0	46

extra work adjustments. Finally, the longer the expected duration of a project, the more likely the contract experiences ex post extra work adjustments.[10]

Summary statistics for the ex post changes and the auction data during the sample period are provided in Table 3.1. The relative winning bid (each winning bid normalized by the project's engineering cost estimate) shows that the bidders bid aggressively, indicating that winning bids are 3.2 percent below the engineering cost estimate. However, the relative final payment which is each final payment (winning bid plus adjustment amount) normalized by the project's engineer cost estimate is 2.5 percent above the engineering cost estimate. In our sample, the mean adjustment is $114,566 while the transfer of extra work in that adjustment is on average $105,713, or about 5.7 percent and 5.8 percent of the engineer cost estimate, respectively.[11] These figures show that the significant component of the

[10]Even though Figures 3.1 and 3.2 support that uncertainty plays a major role in the occurrence of extra work adjustments, we will provide stronger evidence with the empirical analysis in subsection 3.3.3.

[11]Renegotiations in public procurement are frequent and their impacts on the economy are significant. Previous literature shows that ex post changes are substantial in any industry. Bordat, McCullouch, and Sinha (2004) find that cost overruns are almost 9% of total contract amounts and 12% of all contracts experience time delays using data from 1995 to 2002 in the Indiana highway construction industry. Oudot (2006) documents that 56% of contracts are renegotiated, increasing the price by an average of 4.6% in the French defense procurement industry. Guasch (2004) reports that 54.4% of contracts in the transportation sector in Latin America during 1990s experienced renegotiations.

discrepancy between winning bids and final payments can be attributed to extra work in the projects. The average number of bidders is 3.349 per contract. This implies that the Vermont road construction industry has lower competition level relative to other states because Vermont is smaller state with fewer local construction firms.[12] On average, contractors are expected to take 262 working days to complete their projects. The complexity of the project is defined as the number of different unique pay items in the contract and on average projects consist of 60.228 items. On average about 4 items are added to original contract ex post with high variations across projects in our sample. This table shows noticeable heterogeneity across projects and indicates that it is necessary to control for auction heterogeneity in the empirical analysis presented in the next section.

Tables 3.2 and 3.3 provide further details about summary statistics for the extra work adjustments across years and project types. The size of projects awarded or extra work amounts are constant over all periods, while there is noticeable heterogeneity in the value of projects awarded, as well as extra work adjustments across project types: the mean value of extra work adjustments in highway projects is $140,677 making up 6.43% of construction project value. The most dominant type of projects in our sample is highway construction contracts.

[12] On average, the number of bidders per auction is 1.1 lower than that in California, see Bajari, Houghton, and Tadelis (2014) for more detail.

Table 3.2: Summary statistics of contracts by year of award

Year	Number of Contracts	ECE ($) Mean	ECE ($) SD	EWA ($) Mean	EWA ($) SD	EWA/ECE Mean	EWA/ECE SD
2004 After May	17	2,754,339	4,384,505	298,982	531,681	0.169	0.284
2005	54	1,793,051	1,695,207	144,071	271,709	0.075	0.118
2006	59	1,496,737	1,586,579	69,829	151,229	0.047	0.088
2007	51	2,232,715	3,648,056	96,639	376,236	0.043	0.072
2008	53	1,722,999	1,872,332	116,135	264,957	0.065	0.113
2009	78	2,036,507	2,145,181	63,030	140,247	0.034	0.091

ECE refers to Engineer Cost Estimates and EWA refers to Extra Work Amount.

Table 3.3: Summary statistics of contracts by project type

Project Type	Number of Contracts	ECE ($) Mean	ECE ($) SD	EWA ($) Mean	EWA ($) SD	EWA/ECE Mean	EWA/ECE SD
Highway	164	2,473,540	3,043,610	140,678	346,265	0.064	0.137
Bridge	117	1,396,333	1,173,448	74,591	155,540	0.051	0.097
All other Projects	31	869,658	1,330,259	38,201	68,886	0.046	0.072

ECE refers to Engineer Cost Estimates and EWA refers to Extra Work Amount.

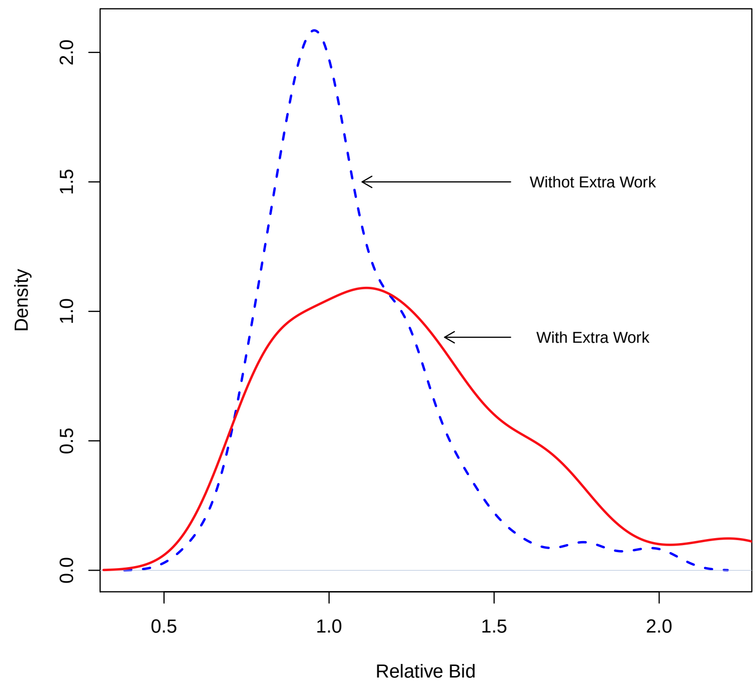


Figure 3.3: Density distribution function of relative bids

Figure 3.3 presents the non-parametric kernel density plot of the relative bid distributions of contracts with ex post extra work adjustment shown along with contracts without the adjustment. The relative bid is measured as the ratio of the bid to the engineering cost estimate.[13] It illustrates that bidders place less aggressive bids ex ante in projects with ex post extra work adjustments than they do in projects with no adjustment. Note that the size of this adjustment implies the degree of incompleteness in the initial contracts. This bidding pattern is more pronounced at the upper tail of the distribution. This figure seems to suggest that bidders incorporate ex post possible adaptation costs into their bids ex ante when they anticipate changes in scope of work in projects. We will discuss this issue in

[13]Note that we obtain Gaussian kernel estimates on a random sample of relative bids by considering Silverman's "rule of thumb" bandwidth selection. We consider only projects with extra work adjustment or projects with no adjustment at all. Then, we have only 281 bids, in which 105 bids are from projects with the adjustment and 176 bids are from projects without the adjustment.

more detail next section.

3.3 Empirical Analysis

A structural approach is widely used in empirical auction literature by assuming that the observed bids are the Bayesian Nash Equilibria of the theoretical model. In this section, we present a simple bidding framework describing firm's bidding behavior in anticipation of ex post extra work adjustment. We assume that bidder's bidding strategy is strictly monotonic and differentiable. We derive equilibrium bidding functions assuming that bidders have prior beliefs regarding the likelihood of the adjustments. Then, we employ nonparametric estimation methods similar to the ones in Haile, Hong, and Shum (2006), Bajari, Houghton, and Tadelis (2014), and Guerre, Perrigne, and Vuong (2000) to estimate the primitive costs using observed bids.

3.3.1 Equilibrium bidding behavior

Vtrans procures projects using a competitive auction, which is the most common method of procurement in the transportation construction industry. A project is characterized by a list of T tasks indexed $t = 1, \ldots, T$. Engineers in the transportation department provide their original plans including the estimated quantity for each task q_t^e (in vector notation $\mathbf{q}^e = [q_1^e, \ldots, q_T^e]$). Each bidder submits sealed unit price bid for every task. b_t^i denotes bidder i's unit price bid on task t (in vector notation $\mathbf{b}^i = [b_1^i, \ldots, b_T^i]$). Let $s^i = \sum_{t=1}^{T} b_t^i q_t^e = \mathbf{b}^i \cdot \mathbf{q}^e$ be a score which is the vector product of unit prices and estimated quantities. In low price sealed bid auctions, the bidder with the lowest s^i is awarded the contract.[14] Then, the probability

[14]In Oklahoma if the bid is more than 7% above the engineering cost estimate it will be officially rejected while VTrans has no formal threshold for rejecting bids. VTrans may reject an irregular bid if some items have bids of zeros. However, these are extreme cases in the real world.

that bidder i's score, s^i, is greater than bidder j's score, s^j, 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, $\prod_{j \neq i}(1 - H_j(s^i))$ denotes the probability of bidder i's winning the auction with a score s^i. Payment to the winning bidder is based on quantities used multiplied by winner's bid prices ($\mathbf{b}^i \cdot \mathbf{q}^e$) plus ex post extra work adjustment amount of $\mathbf{A}$. The adjustment amount includes the production costs of performing the additional work and the margins that a contractor seeks on the extra work adjustment. Note that the size of this adjustment implies the degree of incompleteness in the initial contracts. We assume that bidders know that a contract is incomplete with the probability of $\mathbf{k}$.[15] Note that we consider only the changes in the scope of work, extra work adjustments, in this structural model although there are other types of adjustments as mentioned in the previous section.

Firm i's expected profit is $((\mathbf{b}^i - \mathbf{c}^i) \cdot \mathbf{q}^e) \times (1 - \mathbf{k}) + ((\mathbf{b}^i - \mathbf{c}^i) \cdot \mathbf{q}^e + \mathbf{A}) \times \mathbf{k}$ if it wins the project and zero otherwise. We define bidder i's expected profit function as follows:

$$\begin{aligned}
&\pi^i(\mathbf{b}^i, \mathbf{c}^i, \mathbf{k}) \\
&= \left[\left(\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot \mathbf{q}^e\right) \times (1 - \mathbf{k}) + \left(\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot \mathbf{q}^e + \mathbf{A}\right) \times \mathbf{k}\right] \times \left[\text{pr}\left(\mathbf{b}^i \cdot \mathbf{q}^e < \mathbf{b}^j \cdot \mathbf{q}^e\right)\right] \\
&= \left[\left(\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot \mathbf{q}^e\right) \times (1 - \mathbf{k}) + \left(\left(\mathbf{b}^i - \mathbf{c}^i\right) \cdot \mathbf{q}^e + \mathbf{A}\right) \times \mathbf{k}\right] \times \left[\prod_{j \neq i}(1 - H_j(s^i))\right],
\end{aligned} \tag{3.1}$$

The expected profit function defines bidder i's revenue as the bid amount plus expected extra work adjustments ex ante in the contract. The first order condition

[15] This is not a strong assumption. VTrans engineers and contract administration specialists believe that firms are able to anticipate spot errors in plans using their stronger expertise skills and knowledge about a job site that VTrans engineers do not have.

(FOC) is equal to:

$$\frac{\partial \pi^i(\mathbf{b}^i, \mathbf{c}^i, \mathbf{k})}{\partial b_t^i} = \left[q_t^e\,(1-\mathbf{k}) + q_t^e\mathbf{k}\right]\left[\prod_{j\neq i}(1-H_j(s^i))\right] - \left[\left(\left(\mathbf{b}^i - \mathbf{c}^i\right)\cdot \mathbf{q}^e\right)\times(1-\mathbf{k}) + \left(\left(\mathbf{b}^i - \mathbf{c}^i\right)\cdot \mathbf{q}^e + \mathbf{A}\right)\times \mathbf{k}\right]\times\left[q_t^e \sum_{k\neq i} h_k(s^i)\prod_{j\neq i,k}(1-H_j(s^i))\right] = 0. \tag{3.2}$$

Note that $\left[q_t^e \sum_{k\neq i} h_k(s^i) \times \prod_{j\neq i,k}(1-H_j(s^i))\right]$ is equal to $\frac{\partial s^i}{\partial b_t^i} \times \frac{\partial\left[\prod_{j\neq i}(1-H_j(s^i))\right]}{\partial s^i}$. Now we divide equation (3.2) by $\prod_{j\neq i}(1-H_j(s^i))$. Then we have

$$\frac{\partial \pi^i(\mathbf{b}^i, \mathbf{c}^i, \mathbf{k})}{\partial b_t^i} = q_t^e - \left[\left(\left(\mathbf{b}^i - \mathbf{c}^i\right)\cdot \mathbf{q}^e\right) + (\mathbf{A}\times\mathbf{k})\right]\times\left(q_t^e\sum_{j\neq i}\frac{h_j(s^i)}{(1-H_j(s^i))}\right) = 0. \tag{3.3}$$

After simplifying, we write the first order condition as,

$$\left(\mathbf{b}^i - \mathbf{c}^i\right)\cdot\mathbf{q}^e + (\mathbf{A}\times\mathbf{k}) = \left(\sum_{j\neq i}\frac{h_j(s^i)}{(1-H_j(s^i))}\right)^{-1}. \tag{3.4}$$

Equation (3.4) expresses the FOC as a function of $\mathbf{k}$ that is the probability of incomplete contract. On the other hand, if $\mathbf{k} = 0$, then equation (3.4) can be written as follows:

$$(\mathbf{b}^i - \mathbf{c}^i)\cdot\mathbf{q}^e = \left(\sum_{j\neq i}\frac{h_j(s^i)}{(1-H_j(s^i))}\right)^{-1}. \tag{3.5}$$

In subsection 3.3.5, we will uncover the latent project cost distributions with these equilibrium bidding functions.

3.3.2 Selected sample data

The identification and estimation of equations (3.4) and (3.5) require a sample of projects that are more homogeneous and fit the Independent Private Values (IPV) framework for the known components of the cost. We assume that under the IPV environment with ex post extra work, where each bidder knows his own cost for every task on the original contracts while he is uncertain about the unknown components of extra work. We use the following adjustments to the sample to obtain a more homogeneous subsample. First, we select projects with extra work adjustments only or projects without any renegotiation and then restrict the sample to projects with estimated costs of less than 5 million dollars. Second, we obtain a subset of project with similar level of competitiveness by restricting the sample to projects with two or three bidders.[16]

In our analysis, we define two subsets of projects denoted by $\mathcal{S}_T$ and $\mathcal{S}_C$. Let n_a^e denote the number of items on the original contract in an auction a while we define n_a^m as the number of items actually used in the field. The subset of interest is $\mathcal{S}_T = \{a : n_a^m > n_a^e,\ a \in \mathcal{A}_T\}$, where $\mathcal{A}_T$ is a set that includes construction contracts with extra work adjustments. The subset of projects that are not renegotiated is defined as $\mathcal{S}_C = \{a : n_a^m = n_a^e,\ a \in \mathcal{A}_C\}$, where $\mathcal{A}_C$ includes projects in which there is no renegotiation at all. Notice that the size and number of tasks are much more similar across projects in the subsample than those in Table 3.1.

[16] Later in this study, we will consider different threshold values to check the robustness.

Table 3.4: Data Description

	Extra Work Adjustment ($\mathcal{S}_T$)					No Adjustment ($\mathcal{S}_C$)				
	Obs	Mean	Std	Min	Max	Obs	Mean	Std	Min	Max
Bid Amount (\$)	41	757,851	848,465	58,347	3,293,631	75	806,772	841,258	24,952	4,869,724
Engineer Cost (\$)	41	638,303	821,965	50,135	3,697,137	75	795,494	866,544	26,224	4,907,971
Relative Bid	41	1.261	0.379	0.757	2.218	75	1.050	0.237	0.615	2.000
Number of Items	41	35.366	20.718	7	77	75	38.627	29.814	2	105
Calendar Days	41	163.098	92.159	60	343	75	152.720	107.335	14	392
Number of Bidders	41	2.659	0.480	2	3	75	2.627	0.487	2	3

3.3.3 Reduced form estimation

In this subsection, we empirically model the log of the firm's bid as a linear function of an extra work indicator, auction specific characteristics and a set of bidder specific characteristics. Here only projects with extra work adjustments or projects with no renegotiation at all are considered. The equation to be estimated is as follows:

$$ln(b_{ia}) = \beta_0 + \beta_1 EX_a + \boldsymbol{\gamma}'\mathbf{X}_i + \boldsymbol{\delta}'\mathbf{Z}_a + \alpha_i + u_{ia}, \tag{3.6}$$

where the dependent variable is the logarithm of bid submitted by bidder i in auction a and EX_a is an indicator for whether auction a experiences extra work renegotiations. $\mathbf{X}_i$ controls for bidder specific characteristics and $\mathbf{Z}_a$ controls for auction level variables. The firm specific control variables include a firm's distance from the work site as well as its rival's minimum distance from the work site, and a dummy variable indicating if a firm is a top firm.[17] The auction specific variables include log of engineer's cost estimate, log of expected calendar days to complete a project, number of project items, number of bidders, and project type dummy. These control variables are similar to the ones employed in Bajari, Houghton, and Tadelis (2014). Our regression model also controls for firm fixed effects that will account for firms' different efficiency levels.

Table 3.5 presents our estimation results for bid function regressions. We report cluster-robust standard errors where clustering is at the auction level. Column (1) displays the results from estimating equation (3.6) with the full set of bidders while column (2) presents the results with only our selected subsample with two or three bidders. The variables related to size or duration of projects have the expected impact as stated in previous literature on bidding behavior. Bidders bid

[17]We assign a top firm if its value of projects won is greater than 6 % of the value of contracts awarded each year. By employing the threshold, we are able to assign a similar proportion of top firms to that in Bajari, Houghton, and Tadelis (2014).

less aggressively in larger value and longer duration projects. The variable on the number of bidders is negative and statistically significant in column (1). As the number of bidders rise in an auction, bids will be lower due to higher competition at the awarding process. The variable is no longer statistically significant in our subsample because there is less variation on the number of bidders as we define the subsample. The variable of top firm indicator is not statistically significant. It is not surprising that top firms have no superior information on unobserved components when uncertainty is common to all firms. Lastly, the bidder and rivals' distances to the project work site are not statistically significant in this bid regression.

One's natural concern in this analysis is that when we define two subsets of projects in subsection 3.3.2, it generates the possibility of a type of selection bias. If it is true, there is a potentially different bidding pattern between projects that have ex post extra work adjustment and projects that do not have the renegotiation. We overcome the possibility of a type of selection bias by employing our homogenized subsample of projects. The binary variable of extra work adjustment is significant in the projects with the full set of bidders, while the indicator variable is not statistically significant when using our subsample with 2-3 bidders. This result suggests that extra work adjustments are randomly assigned, conditional on observable covariates and that our identification strategy of comparing across projects in the subsample is not introducing additional selection bias.

Column (3) in Table 3.5 displays the results for the probability model estimations. We estimate the probability of the occurrence of an extra work adjustment conditional on variables which control for size and proxy for project uncertainty. In this specification, we control for a common set of basic project characteristics including log of engineer's cost estimate, log of expected calendar days to complete a project, the number of project items, number of bidders and elevation of work site. In particular, the log of expected calendar days and the number of project items

Table 3.5: Regression Results for a Model of Bids

Independent Variable	Project Bids: Full Set of Bidders	Project Bids: 2-3 Bidders	Probit Model: Full Sample
	(1)	(2)	(3)
Extra Work Indicator	0.088*	0.054	
	(0.047)	(0.049)	
Log of Engineer's Estimate	0.901***	0.966***	-0.016
	(0.033)	(0.041)	(0.102)
Log of Calendar Days	0.107**	0.165***	0.404***
	(0.041)	(0.053)	(0.125)
Number of Items	-0.091	-0.147	1.666***
	(0.133)	(0.137)	(0.425)
Number of Bidders	-0.037***	0.060	-0.027
	(0.013)	(0.049)	(0.045)
Elevation of Work Site			0.046*
			(0.024)
Top Firm	-0.013	-0.155	
	(0.070)	(0.118)	
Distance to the Project Location	0.035	0.081	
	(0.062)	(0.067)	
Rival's Minimum Distance to the Project Location	-0.020	0.063	
	(0.059)	(0.062)	
Asphalt Project	0.047	0.015	
	(0.077)	(0.061)	
Bridge Project	0.051	-0.046	
	(0.081)	(0.118)	
Firm Fixed Effects	Yes	Yes	No
Observations	281	116	312
R^2	0.970	0.988	
LR χ^2			70.57

*** Denotes statistical significance at the 1% level, denotes significance at the 5% and * denotes significance at the 10% level.

are typically used in empirical auction literature to proxy for the uncertainty of the project. The fitted probabilities for projects are used for probability estimates of the adjustment, $\hat{\mathbf{k}}$, in our structural analysis. We assume that any bidder within the same auction has the same belief on ex post extra work adjustment.

The coefficients on the proxy variables that represent project uncertainty are positive and statistically significant, indicating that uncertainty is the critical determinant of the likelihood of ex post extra work adjustments. Indeed, engineers in the transportation department are likely to fail to provide complete designs or plans for larger and more complex projects. As emphasized in Tadelis (2012), the complex and incompletely specified projects are key reasons for ex post renegotiation. The estimated probability of an extra work adjustment is, on average, 71 percent during the sample period. When we construct the probability of extra work adjustment differently, by dividing the number of occurrences of such adjustments by the number of projects, results do not change from the one we estimated from the probability model regression.[18]

3.3.4 Structural estimation

In this section we employ a structural approach like 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 extra work adjustment. We estimate the bid distribution nonparametrically with directly controlling for auction heterogeneity from the observed bids in the first stage. Given a sample of pseudo costs, we estimate the density of bidders' latent costs in the second stage. We assume that bidders are asymmetric in the sense that there is significant difference in productivity and work experiences across firms in

[18]Note that in Table 3.5 the unit of observation is bid submitted by an individual bidder in the bid regressions while the unit of observation is contract in this probability model, and we utilize all projects in our sample dataset for the probability estimation.

the road construction industry.

Failure to control for many auction-specific cost shifters in a structural analysis will cause estimates of costs to be biased because auction specific characteristics are correlated with the occurrence of extra work adjustment. For example, estimated costs will be under-estimated on small valued (or less complex) projects while they will be over-estimated on large valued (or more complex) projects. Following the methods used by Bajari, Houghton, and Tadelis (2014), we directly control for auction heterogeneity from observed bids in the first step of the two-step process.

There are two types of projects, indexed by r: those that have ex post extra work adjustment and those that have no renegotiation (r=1, 0 respectively). We first estimate a model of the level of bids with the similar specification to that presented in column (2) of Table 3.5.

$$s_{rj}^{(a)} \equiv \mathbf{b}_{rj}^{(a)} \cdot \mathbf{q}^{e(a)} = \boldsymbol{\mu}'\mathbf{x}_{rj}^{(a)} + \boldsymbol{\theta}'\mathbf{z}^{(a)} + \varepsilon_{rj}^{(a)} \tag{3.7}$$

where the dependent variable $s_{rj}^{(a)}$ is a project bid amount by contractor j in auction a. The vector $\mathbf{x} \in \mathcal{X} \subset R^{p_x}$ controls for firm specific effects while the vector $\mathbf{z} \in \mathcal{Z} \subset R^{p_z}$ controls for auction specific effects. The cumulative distribution function of contractor j's score is obtained as follows:

$$\begin{aligned} H_{rj}^{(a)}(s) &\equiv Pr(\mathbf{b}_j\mathbf{q}^e \leq s_r^i) = Pr\left(\boldsymbol{\mu}'\mathbf{x}_{rj}^{(a)} + \boldsymbol{\theta}'\mathbf{z}^{(a)} + \varepsilon_{rj}^{(a)} \leq s_r^i\right) \\ &\equiv G\left(s_r^i - \boldsymbol{\mu}'\mathbf{x}_{rj}^{(a)} - \boldsymbol{\theta}'\mathbf{z}^{(a)}\right) \end{aligned}$$

Therefore, the distribution of residuals $\varepsilon_{rj}^{(a)}$ is used to derive the distribution of the observed bids. We assume that $\varepsilon_{rj}^{(a)}$ are i.i.d in the bid function regression. The fitted residuals $\hat{\varepsilon}_{rj}^{(a)}$ from the regression in the first stage can be used to estimate bid density $h_{rj}(\cdot)$ and distribution $H_{rj}(\cdot)$ for projects with and without the extra work adjustment. We choose here a triweight kernel to estimate these density and distribution functions.

$$K(u) = (35/32)(1 - u^2)^3 1\{|u| \leq 1\}.$$

Furthermore, we employ the bandwidth of the form $w_r = \kappa \hat{\sigma}(\widehat{\varepsilon}_{rj}^{(a)})(n_r L_{rj})^{-1/6}$, where $\sigma(\widehat{\varepsilon}_{rj}^{(a)})$ is the estimated standard deviation of $\widehat{\varepsilon}_{rj}^{(a)}$, $\kappa = 2.9878 \times 1.06$, and L_{rj} is the number of auctions in which a bidder j participated.

Given the estimates $\hat{h}_{rj}(s^i)$ and $\hat{H}_{rj}(s^i)$ we are able to estimate pseudo-values of project costs in the sample of $\mathbf{c}_0^i$ and $\mathbf{c}_1^i$ by solving the following two equations.

$$(\mathbf{b}_0^i - \mathbf{c}_0^i) \cdot \mathbf{q}^e = \left(\sum_{j \neq i} \frac{\hat{h}_{0j}(s^i)}{(1 - \hat{H}_{0j}(s^i))} \right)^{-1} \tag{3.8}$$

$$\left(\mathbf{b}_1^i - \mathbf{c}_1^i\right) \cdot \mathbf{q}^e = \left(\sum_{j \neq i} \frac{\hat{h}_{1j}(s^i)}{(1 - \hat{H}_{1j}(s^i))} \right)^{-1} - \left(\mathbf{A} \times \hat{\mathbf{k}}\right) \tag{3.9}$$

These cost estimates are then used to construct the relative project cost distributions for projects with and without extra work adjustment in the next subsection. Recall that $\hat{\mathbf{k}}$ is the probability estimates for bidder's belief on ex post extra work adjustment we obtained from the previous subsection.

Next we direct our attention to nonparametrically estimating the distribution over private costs. Figure 3.4 shows the estimated relative project cost distributions for projects with and without extra work adjustment. The densities are obtained using the project pseudo costs divided by their corresponding engineering cost estimates. This figure shows that there is a significant cost difference between projects when they are renegotiated for extra work and projects when they are not renegotiated. Increased project costs might result from a number of factors, including adaptation costs. The costs could be significantly high when resolving conflict or litigation from contract dispute when making the agreement for unit price payment

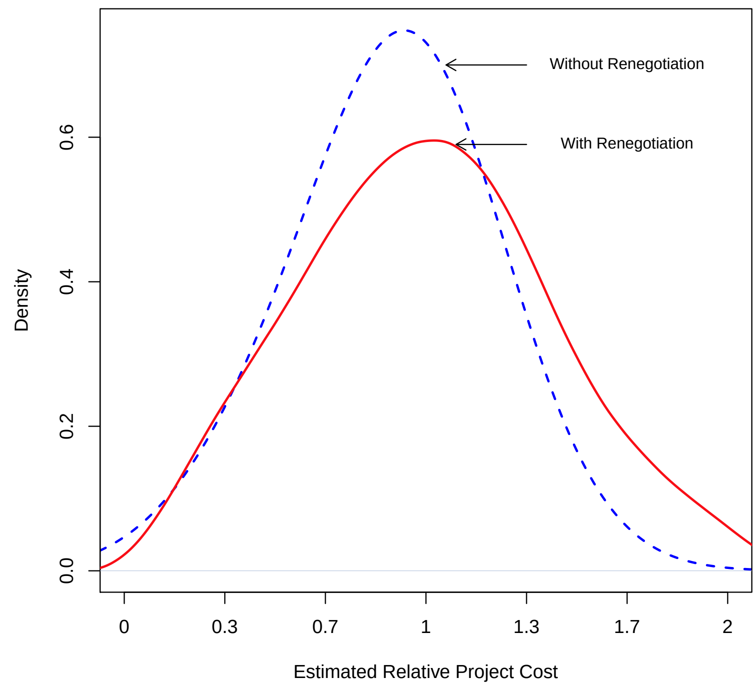


Figure 3.4: Relative cost in projects with and without renegotiation

between two parties.[19] The extra work also requires contractors to extend working days and change their work schedule of ongoing projects or change future projects they are undertaking.

In Table 3.6, we summarize our estimates of bidder markups for projects with and without extra work adjustment. Markups could be associated with project uncertainty, bidder's strategic bidding behaviors, or contractor's internal level of efficiency. The estimation results show that, once we control for project heterogeneity, there is little difference in markups between projects with and without the adjustment. We already showed that extra work adjustments increase project costs. These findings imply that bidders inflate their bids based on their ex ante beliefs on extra work adjustments to incorporate risk premiums for project uncertainty.

[19] Guccio, Pignataro, and Rizzo (2012) also find that legal dispute as well as complexity of projects is one of key determinants of adaptation costs in Italian public work.

Table 3.6: Markups for projects with and without renegotiation

	Percentile						
Group	20%	30%	40%	50%	60%	70%	80%
With Renegotiation ($\mathcal{S}_T$)	4.232	4.690	5.662	8.570	12.020	27.900	61.240
Without Renegotiation ($\mathcal{S}_C$)	2.188	3.424	4.938	7.900	11.500	25.120	48.260

Table 3.7: Tests for invariance of cost distributions to renegotiations

	With Renegotiation			Without Renegotiation			Tests
	Median	Mean	SD	Median	Mean	SD	(KS)
Project Markups(%)	8.567	25.350	30.639	7.903	22.680	28.530	0.595
Relative Project Cost	1.045	1.000	0.568	0.906	0.826	0.334	0.026

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

However, this bidding behavior does not affect profit margins.

We provide non-parametric tests for equality of two project distributions in Table 3.7. The column marked as (K-S) provides p-values corresponding to the Kolmogorov-Smirnov test. We use the statistic to evaluate location shifts between two distributions in projects with and without extra work adjustment. The table shows that we fail to reject the null of equality of project markup distributions while the difference in relative project cost distributions is statistically significant at the 5% significance level.

3.3.5 Adaptation cost and time delays

Next, we calculate the adaptation costs using a similar way proposed by Guccio, Pignataro, and Rizzo (2012). We define the adaptation cost as follows[20]:

$$AC_j^{(a)} = \frac{FC_j^{(a)} - B_j^{(a)}}{B_j^{(a)}} \tag{3.10}$$

[20]Note that Guccio, Pignataro, and Rizzo (2012) employ only the winning bids instead of all bids in a contract. Unlike their analysis, the adjustment amounts across bidders in the same auction could be very similar in this analysis because we have used only the contracts with extra work adjustment that might be independent of bidder's bid skewing.

where, $FC_j^{(a)}$ is the final costs paid by VTrans and $B_j^{(a)}$ is bidder j's bid for an auction a. Table 3.8 summarizes the results of calculated adaptation costs in subsample of projects. The adaptation costs are much lower than those reported in the literature. For example, the estimated adaptation costs are on average equal to about 10% of the winning bid in Bajari, Houghton, and Tadelis (2014). However, the previous empirical work employs all of contracts with any types of adjustments, unlike our specifications. The table still shows that adaptation costs are substantial and range from 2.46% to almost 3.02% of bids in contracts with only extra work adjustment.[21] According to Bajari, Houghton, and Tadelis (2014), the adaptation costs may be costs due to legal disputes over ex post extra work and losses due to disrupted workflows. Besides the adaptation costs discussed in the literature, an extra work adjustment may be more costly than any other types of adjustments. For instance, the contractor may spend additional costs on training, research and learning in order to execute extra tasks. Furthermore, contractors would spend even more money if they had little experience with additional tasks required by the adjustment.

Ex post extra work adjustments also cause for time delays that have adverse effects on public. As projects take longer to complete, road commute times will be increased because commuters need to find detours or sit in traffic jams. Time delays are calculated by the number of days of time overrun, which is the proportional difference between the adjusted duration and the expected duration on the original plan in projects. The table shows that time delay rates have averaged approximately 15% to 35% depending on the number of bidders in our sample. The percentage of contracts with time delays is around 84% in projects with extra work adjustment. This table implies that ex post extra work could not only induce monetary

[21] Serag, Oloufa, Malone, and Radwan (2010) show that scope of work changes is the significant type of adjustment when the percentage increase in project costs exceeds 5% in the Florida road construction industry.

Table 3.8: Adaptation costs and time delays of project with extra work adjustment

		Adaptation Cost (%)		Time Delays (%)	
	Observation	Mean	Standard Deviation	Mean	Standard Deviation
Auctions with Full Set of Bidders	105	2.458	4.426	14.715	54.343
Auctions with 2-3 Bidders	41	3.019	3.591	35.244	83.132

adaptation costs, but also lead to significant non-monetary efficiency loss.

3.3.6 Robustness checks

To check on the robustness of our main results, we estimate alternative specifications. A potential concern when estimating the bidding function is the possibility that the top firm variable is endogenous in the estimation model. For instance, more experienced and larger firms are likely to participate in the auctions of very complex projects due to their financial strength or experience with similar works. As a robustness check, we proceed to implement two stage least squares approach to correct for the possible endogeneity of the top firm variable. In particular, we use the firms' assets and their costs of revenues to capture exogenous shift to top firm.[22] In Table 3.9, we present evidence that the cost and markup estimates with our identifications are robust to this change in specification. We have consistent results that there is little difference in markups while there are significant differences in costs between projects with and without extra work adjustment.

Another potential concern in the literature is the possibility of bidder's endogenous entry. It would require one to explicitly model the participation decision of bidders.[23] In this analysis, the possibility of ex post extra work adjustments might

[22] The regression is overidentified because there are two instruments and a single included endogenous variable. We perform the tests of overidentifying restrictions and fail to reject the null hypothesis that both instruments are exogenous.

[23] Table 3.10 shows that there is no systematic relationship between the winning bid and the engineer cost estimate as the number of bidders varies. This implies that we might be able to preclude the possibility of endogenous entry problem in this analysis as Decarolis (2013) does.

Table 3.9: Robustness Checks: Tests for invariance of cost distributions to renegotiations

		With Renegotiation			Without Renegotiation			Tests
		Median	Mean	SD	Median	Mean	SD	(KS)
(1)	Project Markups(%)	8.384	27.850	32.409	8.980	22.930	29.014	0.529
	Relative Project Cost	0.988	0.945	0.551	0.907	0.818	0.339	0.086
(2)	Project Markups(%)	6.422	15.340	18.997	5.372	14.250	19.309	0.391
	Relative Project Cost	1.079	1.146	0.489	0.944	0.928	0.258	0.023

(1): The first robustness check, (2):The second robustness check
The last column of the table provides p-values corresponding to the Kolmogorov-Smirnov (KS) test.

Table 3.10: Summary statistics by number of bidders

Number of bidders	Number of contracts	Engineer Cost Estimate ($)		Winning Bid ($)	
		Mean	SD	Mean	SD
1	40	2,692,485	2,540,769	2,729,287	2,471,700
2	77	1,953,004	1,732,838	1,887,547	1,643,908
3	86	2,010,502	2,717,439	1,840,979	2,502,389
4	46	1,078,295	947,005	1,059,312	872,181
5	24	2,683,985	4,847,995	2,424,487	4,325,751
6	16	1,644,321	1,590,080	1,452,842	1,538,733
7	7	1,056,112	640,015	848,921	585,047
8	7	1,591,904	1,688,410	1,425,900	1,627,084
9	5	742,913	479,255	555,194	392,797
10	1	432,224	-	246,470	-
11	3	665,930	97,492	487,662	127,787

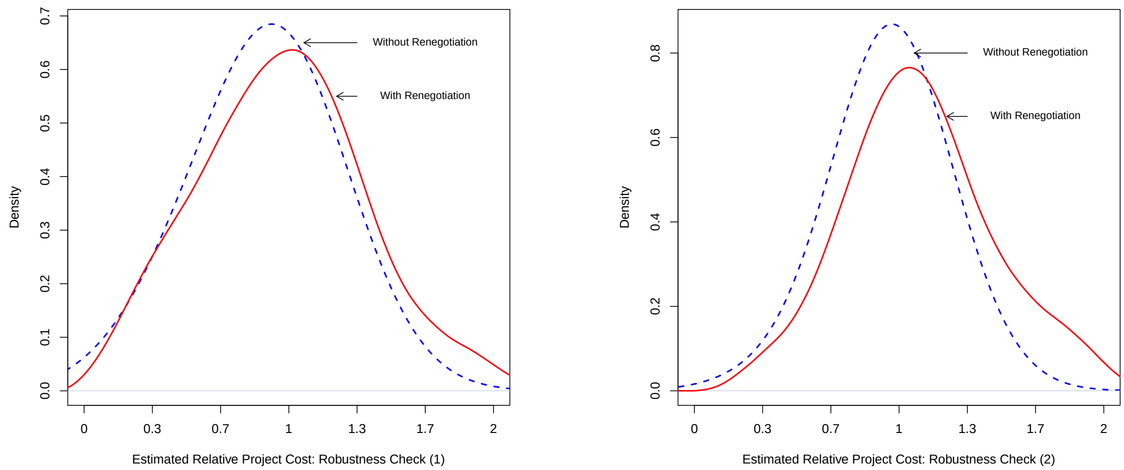


Figure 3.5: Robustness Checks: Relative cost in projects with and without renegotiation

affect bidder's entry decision in auctions with and without the adjustments. To address this issue, we employ the expected number of bidders in place of actual number of bidders in the first stage regression. The expectation of the number bidders is constructed using the past year information on bidding history for all plan-holders. First,we calculate the probability of submitting bids conditional on being a plan-holder. Consequently, the expected number of bidders is equal to summation of these participation probabilities for all plan-holders in an auction at time t (see, De Silva, Dunne, Kankanamge, and Kosmopoulou (2008) for more details). We continue to find statistically significant differences in bidder's costs and no apparent differences in bidder's markups in this alternative specification.[24] Notice that we

There are few theoretical models and empirical tests of endogenous entry in the literature (see, for instance, Levin and Smith (1994) and Athey, Levin, and Seira (2011)). In particular, little progress has been made of endogenous entry with asymmetric bidders in the literature.

[24] We also consider the possibility that the cost distributions depend on the number of bidders. If exogenous variation of bidders holds, the cost distributions for $n = \mathcal{N}$ are invariant in a private value model (see Lemma 1, Haile, Hong, and Shum (2006)). We tried different levels of participation for this alternative specification, e.g. n =2, 3, 4 or 5. The estimation results with these values consistently show significant differences in the overall cost of procurement. Note that the estimated markups are significantly higher than the ones presented in Table 3.6. The market becomes less competitive in this alternative specification due to smaller number of bidders. Previous auction literature finds that less bidders will generate a higher expected bid in independent private value

omit the bid regression results in our alternative specifications because they yield similar estimates. The results are consistent with previous findings and are available upon request.

3.4 Conclusion

This paper contributes to the empirical literature on auctions by providing an examination of how incomplete contracting in procurement affects costs on road construction contracts. This analysis uses the structural model to estimate the distribution of latent costs after controlling for project heterogeneity. Unlike previous literature, we include bidder's ex ante belief that particular projects will have ex post extra work adjustments. Our empirical results highlight a significant difference in costs between projects with and without extra work adjustment. Increased project cost could be a result of a number of factors, including adaptation costs from work flow disruptions and legal dispute resolution for unanticipated work. We also find that bidders inflate their bids to incorporate risk premiums in incomplete contracts.

Information dispersed among bidders about ex post renegotiations plays a role in procurement auctions. Our estimates show that the markups are not statistically different, indicating similar profit margins between projects with and without the adjustment. In particular, there is no evidence of bidders' strategic bidding behaviors in projects with unpredictable work, because the general uncertainty of this work is symmetric information among auction participants. In contrast, we find in Chapter 3 that a few bidders extract more rents by strategic bidding in contracts with positive quantity adjustments. This bidding behavior results from asymmetric information among bidders on change in quantity caused by engineer's errors. The more experienced firms are likely to anticipate actual quantity used

environments. These results are omitted to save space but they are available upon request.

in the field. Then, they have a strong incentive to manipulate their bids with the superior information.

Most procurement fixed price-contracts are awarded through open competitive auction mechanisms. Transportation agencies should be allowed more flexibility in selecting award mechanisms in a highly complex project if they anticipate the possibility of costly renegotiation due to an incomplete contract. Even though fixed price contracts offer strong ex ante incentives for cost minimization, they introduce higher friction when ex post changes are needed (Bajari and Tadelis, 2001). When there is uncertainty or significant complexity in a project, it is argued that cost plus contracts may be preferred because of the flexibility they offer and frequent monitoring that may make it less costly to accommodate ex post adaption. Implementing incentive structures could help to reduce the overall procurement costs in complex or uncertain projects.

Chapter 4

Uncertainty and Contract Renegotiation in Public Procurement[1]

4.1 Introduction

In procurement contracts, ex post renegotiations are often implemented through change orders. Change orders have clear benefits because they implement engineering specifications that address circumstances or conditions that were unforeseen at the time the project was planned and initiated. The costs associated with change orders are of two varieties. The first are direct costs associated with additional materials and labor, which often amount to more than ten percent of total project costs. The second are "adaptation" costs associated with renegotiating the contract. Recent research by Bajari, Houghton, and Tadelis (2014) estimate adaptation costs as between seven and thirteen percent of winning bid amounts. The existence of adaptation costs in particular makes it worthwhile to investigate whether it is possi-

[1]This chapter is based on a working paper coauthored with Georgia Kosmopoulou and Richard Sicotte.

ble to identify factors associated with the incidence and magnitude of change orders. If it appears that change orders are likely given specific identifiable characteristics of the competitive environment, the firms or the project types, it may be preferable for the procuring agency to invest more time on initial designs in a targeted effort rather than to proceed with the project and deal with renegotiations ex post.

There are relatively few studies that consider factors associated with the frequency of renegotiations (see Anastasopoulos, Labi, Bhargava, Bordat, and Mannering (2010), Bordat, McCullouch, and Sinha (2004), Hsieh, Lu, and Wu (2004), Iossa, Spagnolo, and Vellez (2007), and Oudot (2006)). The studies, mostly from the civil and construction engineering literatures, identify uncertainty and complexity as critical determinants of renegotiation. In the economics literature, Bajari, Houghton, and Tadelis (2014) note that if firms anticipate change orders they are likely to incorporate a bid premium into their fixed price bid in order to shield contractors from adaptation costs associated with haggling and renegotiation. Our paper integrates and extends the contributions from these two complementary literatures. We investigate what factors are most closely associated with change orders, employing a dataset of highway and bridge construction projects in Vermont. We estimate models of the number of change orders, and the relative cost of change orders. We hypothesize that contract renegotiations arise from uncertainty about the true nature of the project, and that these uncertainties are correlated with certain observable project-level characteristics, such as the location, size and expected duration of the project. We also hypothesize that some idiosyncratic project-level characteristics that correlate with such uncertainty may not be observable by econometricians or even the state engineers, but are in fact known to one or more of the firms bidding on the project. For example, if the winning bid exceeds considerably the state engineer's estimate, part of this "bid premium" may reflect the anticipation of adaptation costs associated with possible change orders. The incentive to include this premium exists because although firms will be compensated for any change in labor and materials employed, they will have to bear the aforementioned adaptation costs. We also test the hypothesis that the lower the winning bid is relative to the second lowest bid, the more likely it is that the winning bidder actually misjudged the true nature of the project and that the other bidder(s) correctly anticipated higher adaptation costs, and therefore incorporated them into their bids. An alternative interpretation is that such variation among bids will lead the winning bidder to more aggressively pursue and argue for change orders ex post. We expect that the top firms in the market may often have superior information about a project and the market, enabling them to better anticipate change orders and their rivals' bids. When firms have an informational advantage, then for a given number of change orders, their winning bids will be closer to the second lowest bid than when other firms win the bid. We test the hypothesis that projects won by top firms are more likely to have change orders. This will happen because the most successful firms are more likely to select difficult projects - an endogeneity problem that we must control for - and because such firms have more leverage convincing state employees of the necessity of such changes.

The paper proceeds as follows. Section 4.2 provides a description of the data. Section 4.3 presents empirical results and section 4.4 offers concluding remarks.

4.2 Data and Descriptive Analysis

Before proceeding to the econometric analysis, we first present the salient details of our database on change orders. The data used in this paper contains information on all 312 construction projects auctioned by the Vermont Agency of Transportation (VTrans) between May 2004 and December 2009. Our dataset provides information on projects' scopes, dates, durations, and engineering cost estimates. We have full

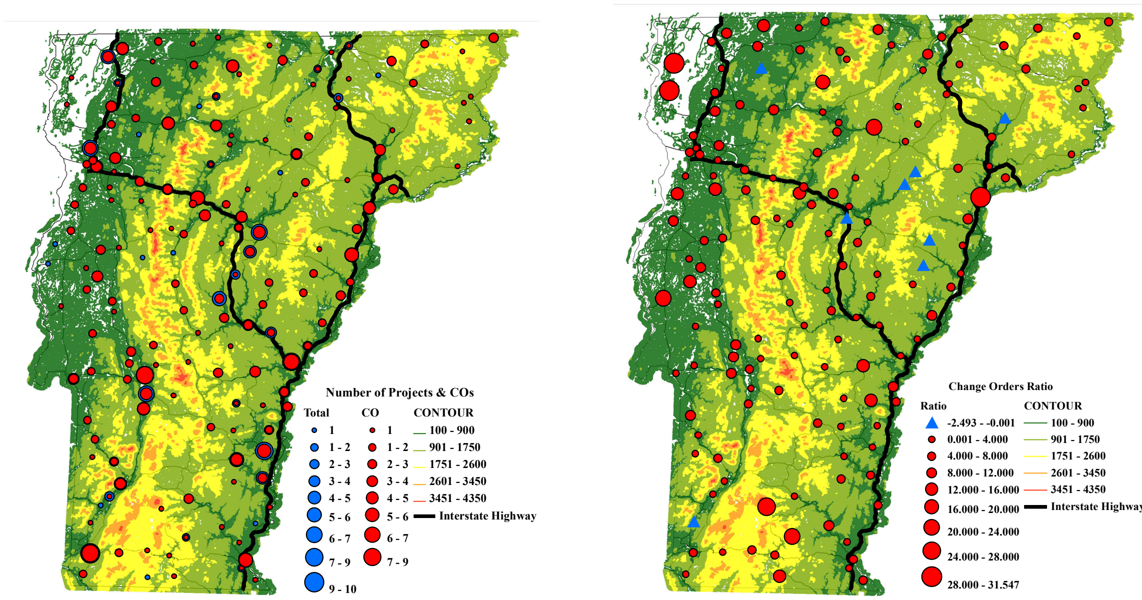


Figure 4.1: Project Locations and Change Orders in the Vermont Highway Construction Industry

information on the change orders for each project, including the changed quantity and unit-price for each renegotiated item within a contract, with a brief description of reasons for that change. Regulation requires that change orders are filed if the changes of plans or specifications impose at least a 5% increase in costs. Renegotiations are often significant. In our sample, 81% of contracts were renegotiated resulting in an average cost increase of 6.22% over the winning bids. Over the period of analysis VTrans spent an average of $105,200 on renegotiations per contract. Most change orders include some renegotiation about the use of unanticipated materials in the field.

The maps in Figure 4.1 show the spatial distribution of contracts and their likelihood of renegotiation.[2] There are blue and red marks displayed on the figure that vary in size by the number of contracts procured and renegotiated. Red marks are

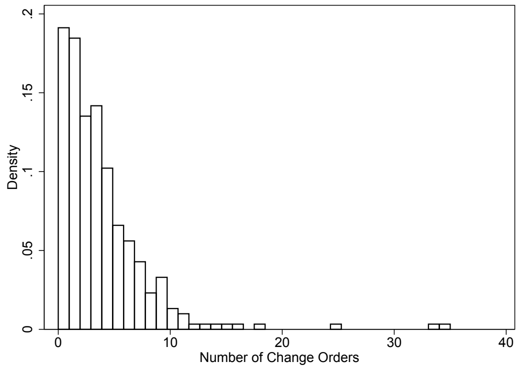
[2]When we count the number of change orders, we exclude those change orders that only include price adjustments. These are triggered by changes in the prices of fuel and asphalt that are beyond the discretion of either the firm or the Agency. By the same logic, the renegotiated amounts that we calculate omit amounts stemming from price adjustment clauses.

superimposed on the blue marks. A blue ring surrounding a red mark shows that some contracts procured in this region have not been renegotiated. Red marks dominate the picture as renegotiations seem to be widespread. The right panel shows the percentage of contract value renegotiated. It becomes more evident in this figure that the contracts renegotiated in higher proportion are those in remote/less populated areas or in mountainous terrain. There is a lower percentage of renegotiations on the more frequently repaired interstate highways. This figure suggests that the frequency of renegotiation is strictly tied to the level of uncertainty, which should be lower for repeat projects and for easier terrain.

Table 4.1: Bidding and renegotiation activities of 92 firms

Firm ID	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
(1)	71	53.788	35.630	2.211	-0.035	4.463	140.211	60	65	4.801	3.775
(2)	33	33.673	12.053	2.788	-0.053	8.199	175.636	28	30	6.744	3.970
(3)	9	27.273	10.222	4.111	-0.009	9.111	364.445	8	8	4.034	8.889
(4)	8	36.364	4.885	3.375	-0.170	7.006	151.875	4	6	4.288	2.625
(5)	9	15.789	3.752	4.111	0.016	4.201	346.778	9	9	3.183	6.333
(6)	8	22.222	3.393	3.000	-0.046	12.713	218.875	6	7	10.019	5.125
(7)	12	32.432	2.453	5.917	-0.045	6.962	294.000	9	10	6.016	3.583
(8)	8	47.059	1.985	3.500	0.020	8.316	299.000	6	8	2.714	3.250
(Remaining 84 Firms)	154	25.122	25.627	3.714	-0.025	13.073	186.669	94	111	4.828	2.714
All Firms	312	29.856	100.000	3.349	-0.032	8.116	191.619	224	254	5.065	3.478

(A): Number of Wins
(B): Winning (%)
(C): Value of Winning Projects/Value of Procured
(D): Average Number of Competing Bids on Contracts Won
(E): Average Winning Bid Deviation from Engineer Cost Estimate
(F): Average Weighted MLT (%)
(G): Average Expected Duration of Contract Won (days)
(H): Number of Contracts with New Items Added
(I): Number of Contracts Renegotiated
(J): Average Value of Change Orders/Winning Bid on Project (%)
(K): Average Number of Change Orders per Project



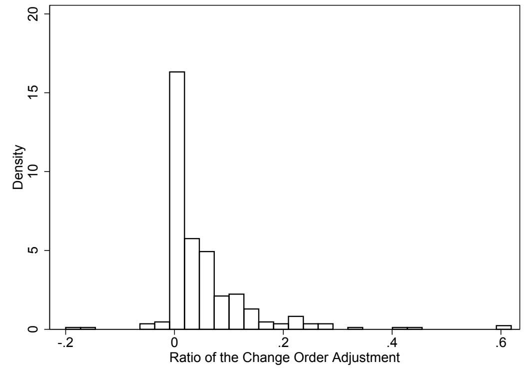


Figure 4.2: Histograms of the Number of Change Orders and the Ratio of Change Order Amounts to Winning Bids

Finally, Figure 4.2 presents histograms of the number of change orders, and the ratio of the change orders' costs to the winning bid. The histograms show distributions that are heavily skewed. While the average number of change orders on projects is 3.478, 10.58% of projects have more than seven change orders. Similarly, on the average project the cost of change orders constitutes approximately five percent of the winning bid amount, but on nearly twenty percent of projects change orders costs exceed ten percent of the winning bid.

4.3 Empirical Analysis

We first study the probability that one more change order is filed in a project. Our dependent variable is the number of change orders submitted (y) for a given contractor (i) in auction (a). The estimation of a count model with the standard Poisson regression model is specified as follows.[3]

$$y_{ia} = exp(\alpha w_{ia} + X_{ia}'\beta) + \varepsilon_{ia}$$

[3]The Zero-inflated models are useful alternatives proposed in the literature (See Cameron and Trivedi (2005) and Hilbe (2011) for more details) when there is an excess of zeros generated by a distinct process from the count values. This is not the case in our model. As shown by Figure 4.1 only 18.59% of projects have no renegotiation.

where ε_{ia} an additive idiosyncratic error term and X_{ia} is exogenous, such that $E(\varepsilon_{ia}|X_{ia}) = 0$. Our empirical model incorporates a common set of project characteristics including project size measured by the engineering cost estimate, the estimated duration of a project and the number of items needed to complete the project. Both the estimated duration and the number of items are variables typically used in the literature as proxies for the degree of uncertainty in a project. We anticipate a positive relationship between these uncertainty proxies and the number of change orders. We also use the number of bidders to measure the degree of competition in the market.[4] To control for systematic differences across types of projects, we use three binary indicators (road construction, bridge construction and miscellaneous projects). We have no priors about the expected number of bidders or the type of project. We account for differential work site conditions by using the elevation information of each project, which enters in quadratic form. We hypothesize that higher elevation projects entail greater engineering complexity, and therefore are more susceptible to change orders.

We include two variables based upon bidding behavior, as defined in the previous section. The first is the deviation between the winning bid and the engineer's cost estimate and the second is the "money left on the table" by the winning bidder. Both can be interpreted as indicators of disagreement between the winning bidder and the engineers on the one hand, and between the bidders themselves on the other. Positive deviations between the winning bidder and the engineer's estimate are consistent with the inclusion of a bid premium in the presence of uncertainty.

[4]Due to the concern of endogenous entry, we use the expected number of bidders instead of the actual number of bidders in this analysis, considering whether the plan holders' identities are publicly announced prior to the letting. It is calculated using information over the past twelve months 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 a dummy variable by the expected number of bidders in order to identify auctions in which there are more than three qualified plan-holders on the plan-holder list. The state releases information on plan-holders' identities only when there are more than three qualified plan-holders.

Insofar as MLT, whereas higher values might be the result of larger differences in costs between the first and second lowest bidding firms, they might also reflect differing firms' expectations about the true nature of the project. We hypothesize that these disagreements are more likely when projects are uncertain, and more susceptible to change orders. Thus we hypothesize that the sign of the coefficient for these variables should be positive.

We include a binary explanatory variable for "top firm", (w_{ia}), which may be endogenous in the estimation model.[5] Large experienced firms may be more likely to submit change orders as their knowledge and experience could help their chances of renegotiation with the state government. The likelihood of renegotiation, however, is higher in bigger, more uncertain projects. Larger contractors are more likely to undertake uncertain projects due to their finances and experiences with similar works. This could create endogeneity concerns in our empirical estimation leading to inconsistent estimates. We address the potential endogeneity bias by using instrumental variables unlikely to impact directly the likelihood of renegotiation but critical in the establishment of firm size. These instrumental variables are firms' assets and their costs of revenues, which are disclosed each year prior to the renegotiation process. This is omitted in prior estimation results in the literature because it is often proprietary. Lastly, in this analysis, we include two controls for changes in the business environment - the unemployment rate and the log of real volume of projects auctioned off in a month.

The results, presented in Table 4.2, are obtained using the generalized method of moments (GMM) estimator. The first column is our baseline specification of the count of change orders, and the second is the same specification with instrumental

[5] We assign a firm as top firm if its value of projects won is higher than 6 percent of the value of contracts awarded each year. By employing the threshold, we are able to separate firms into similar groups shown in Table 4.1 and assign a similar proportion of top firms to that in Bajari, Houghton, and Tadelis (2014). A top firm designation in the model pertains to its ranking during the year before the change order was placed.

Table 4.2: Estimation results

	Number of Change Orders			
Independent Variable	GMM	GMM IV	GMM	GMM IV
Log of Expected Duration	0.368***	0.374***	0.368***	0.386***
	(0.120)	(0.122)	(0.115)	(0.123)
Number of Items	0.006***	0.007***	0.006***	0.007***
	(0.002)	(0.002)	(0.002)	(0.002)
Log of Engineer Cost Estimate	0.258***	0.247***	0.266***	0.218***
	(0.079)	(0.083)	(0.074)	(0.075)
Elevation of Work Site	0.090**	0.098**	0.082*	0.101**
	(0.042)	(0.044)	(0.044)	(0.046)
Elevation of Work Site^2	-0.003*	-0.004*	-0.003	-0.004*
	(0.002)	(0.002)	(0.002)	(0.002)
Winning Bid Deviation	0.669**	0.649**	0.840***	0.824***
	(0.276)	(0.283)	(0.278)	(0.303)
MLT	1.992***	2.028***	1.831**	1.476
	(0.561)	(0.562)	(0.884)	(1.112)
MLT^2	-1.513	-1.533	-1.008	-0.525
	(1.083)	(1.059)	(1.200)	(1.356)
Top Firm	0.149	0.396	0.141	0.657*
	(0.146)	(0.386)	(0.177)	(0.354)
Top Firm*MLT	-	-	1.832	2.544
	-	-	(1.334)	(1.664)
Top Firm*MLT^2	-	-	-9.042***	-9.677**
	-	-	(3.429)	(4.185)
Firm Experience	0.001	-0.000	0.002	-0.002
	(0.002)	(0.003)	(0.002)	(0.003)
Expected Number of Bidders	0.047**	0.047**	0.052**	0.052**
	(0.023)	(0.022)	(0.022)	(0.021)
Unemployment Rate	0.074**	0.084**	0.075**	0.103***
	(0.034)	(0.038)	(0.033)	(0.036)
Log of Real Volume Projects	-0.944***	-0.922***	-0.970***	-0.980***
	(0.232)	(0.241)	(0.236)	(0.266)
Asphalt Project	-0.125	-0.109	-0.153	-0.166
	(0.207)	(0.221)	(0.203)	(0.238)
Bridge Project	-0.302	-0.256	-0.315*	-0.268
	(0.184)	(0.197)	(0.182)	(0.216)
Seasonal Dummies	Yes	Yes	Yes	Yes
Observations	269	269	269	269

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

variables for “top firm”.[6] Consistent with the civil and construction engineering literatures, our estimations strongly support the hypothesis that the complexity of a project is associated with a greater number of change orders. Our indicators of complexity - the expected duration of the project, the number of items involved, and the engineer’s cost estimate of the project - are all statistically significant at the 1% level. We also compute marginal effects of independent variables at their mean.[7] A project that takes 100 days longer to complete than the mean duration of 158 days has 0.497 more change orders. A one hundred thousand dollar increase in engineering cost estimate from the mean of $1.09 million is associated with a change in the number of change orders of 0.058. There is evidence that the terrain is an important predictor of change orders. As an example, when the work site elevation is 530 ft, the predicted number of change orders is 2.407 while at 930 ft the predicted value is 2.831.[8]

Our bidding variables are also statistically significant. The more the winning bid exceeds the engineer’s cost estimate, the higher is the expected number of change orders. A 10% point increase in bid deviation is estimated to correspond to a 0.169 increase in the number of change orders. There is weak evidence that MLT has a quadratic effect. The coefficients on the squared MLT term are nearly statistically significant at the 10% level. The slope of the estimated quadratic regression function is steeper at low values of MLT than at higher values.[9] These results are consistent with the interpretation that greater disagreements between bidders, and between the winning bidder and the state engineer, indicate greater uncertainty surrounding

[6] Windmeijer and Santos Silva (1997) provide conditional moment restrictions with binary endogenous regressors for the GMM to estimate count data models for the number of visits to doctors. See Greene (2009) for a review of count models with endogenous participation including the zero-inflated count models.

[7] We omit the marginal effects to save space but they are available upon request.

[8] Note that the average elevation of the work site is 730 ft.

[9] For example, considering MLT values around the mean level, a change in MLT by 1% is associated with a larger change in the predicted number of change orders if the initial MLT is 7.12% than if it is 14.12%.

the project, and therefore a greater likelihood of unanticipated circumstances arising that lead to contract renegotiation.

There is no evidence in either of these specifications that more experienced firms or top firms are more or less likely to pursue change orders.[10] The results indicate that projects with a greater number of expected bidders have more change orders. Also, projects undertaken when the unemployment rate is higher are associated with more change orders, and there tends to be fewer change orders on projects that are let during months with a larger volume of other projects. If contractors have alternative profitable options, their opportunity costs of losing a chance at bidding in other projects due to extending the length of ongoing projects will be much higher during economic expansions. On the other hand, they may strategically submit change orders and extend completion by including another item to seek rents during subsequent periods of recessions.

We now estimate versions of the model including interactions between "top firm" and the MLT variables. Recall that if top firms have superior information, projects that they undertake will have more change orders for any given level of MLT (or, equivalently, for a given level of change orders, the projects that top firms undertake will have lower MLT). If this hypothesis is correct, the coefficient on the interaction between "top firm" and MLT will be positive. Columns three and four of Table 4.2 contain the results from specifications including the interaction terms. The Top Firm-MLT interaction terms are not statistically significant in either, although they nearly are when Top Firm is instrumented. The magnitude of the coefficients, however, is greater than the size of the coefficients on MLT, which have diminished in size and - in the case of the IV estimation - lost statistical significance. The inter-

[10]Since we have more instruments than the number of endogenous variable the Hansen's J test of over identifying restrictions is performed. The test fails to reject the null that the overidentification restrictions are valid, giving us the confidence that our instrument set is appropriate. We also tried different threshold values for top firm assignment, e.g. 2-10%, and are assured that our findings are robust to the threshold value.

action terms between Top Firm and the square of MLT are statistically significant in both specifications at the 5% level or better. Moreover, the IV estimation now indicates that Top Firm are more likely to submit change orders, after controlling for endogeneity bias. The estimated coefficient of 0.657 is statistically significant at the 10% level. The model predicts that a project with characteristics at the mean levels that is carried out by a top firm will have 1.726 more change orders than a project with those same characteristics carried out by a fringe firm. Nearly all of this increase is due to the top firm dummy; the estimated impact of the interaction between top firm and MLT is very small. We interpret these results as weakly supporting the hypotheses that top firm have superior information and bargaining power leading to more change orders on projects that they undertake.

The imprecision of the estimated coefficients on the Top Firm-MLT interaction suggests the possibility that top firms do not always possess superior information. We explore that possibility by examining the data in more detail. In Table 4.3, we compare the MLT between top firms and fringe firms on projects, as differentiated by the types of change orders that occur. We are particularly interested in comparing the MLT on projects where top firms are the least likely to have an informational advantage with the MLT on projects where they are most likely to have an advantage. When there is uncertainty common to all, as in projects where change orders consist only of new items added (shown in the second row of the table), both fringe firms and top firms leave more money on the table. When the change orders consist of other adjustments, such as quantity adjustments resulting from engineering miscalculations that experienced firms may be able to anticipate, top firms leave systematically lower amounts of money on the table. The ratios of top firms' MLT to fringe firms' MLT range from 0.350 to 0.563 in such projects. Thus, the evidence in Table 4.3 suggests that asymmetric information is especially acute in projects that have change orders with quantity adjustments.

Table 4.3: Comparison of MLT between fringe firms and top firms (310 projects)

	Fringe Firm					Top Firm					
Type	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max	Ratio
No adjustment (set A)	48	0.135	0.194	-0.222	0.920	8	0.108	0.115	0.001	0.261	0.800
New added item adjustment only (subset B_1)	23	0.166	0.220	-0.238	0.749	9	0.157	0.175	0.007	0.457	0.946
Projects with adjustments (subset B_2)	135	0.119	0.136	-0.179	0.914	87	0.067	0.113	-0.213	0.326	0.563
Projects with quantity adjustments (subset B_2^b)	114	0.125	0.145	-0.179	0.914	82	0.068	0.116	-0.213	0.326	0.544
Projects with quantity adjustments (subset $B_2^{b_1}$)	22	0.206	0.173	0.003	0.711	8	0.072	0.174	-0.167	0.287	0.350

Our sample of projects consists of two sets A and B after we exclude two projects with fuel price adjustments only. Set A includes projects in which there is no renegotiation at all while set B includes construction contracts with adjustments. Set B can be split into two subsets B_1 and B_2. Subset B_1 includes projects with new added item adjustments only while subset B_2 is the complement of B_1 in the set B. Given subset B_2, we define B_2^a and B_2^b such that $B_2 = B_2^a \cup B_2^b$. B_2^a includes the projects with no quantity adjustments. Hence, subset B_2^b includes projects with quantity adjustments alone or projects that have quantity as well as other types of adjustments. Lastly, we define subset $B_2^{b_1}$ which is a subset of B_2^b. $B_2^{b_1}$ includes projects that experience quantity adjustments except for any projects with new added item or dropped item adjustments. The ratio indicates the relative aggressiveness in bidding across the two types of firms.

Following this line of reasoning, we estimate our specification with the interaction terms in a subsample of projects that have quantity adjustments. These results are displayed in Table 4.4. The coefficients on the interaction terms of Top Firm with MLT and of Top Firm with the square of MLT become larger and more statistically significant, whereas the coefficients on MLT are smaller and no longer statistically significant. Compared with the full sample, the coefficient on Top Firm diminishes and becomes statistically insignificant, but the coefficients on the interaction terms become larger and increase in statistical significance. We interpret these results as evidence that top firms are able to make use of superior information when bidding on certain projects. Namely, they are disproportionately capable of detecting the likelihood of quantity adjustments and strategically adjust their bids accordingly.

Lastly, in Table 4.5 we present the ordinary least squares and IV regression estimates with the dependent variable, the ratio of change order costs to the original winning bid which is a measure of the costliness of change orders in a project. Here we find results that have some similarities but also some differences with the count models. The expected duration of the project, the bidding measures ("winning bid deviation" and "MLT"), the expected number of bidders, and the unemployment rate are associated with increased costs due to change orders. For example, extending the expected project duration by 100 days from its mean is associated with 1.9% point rise, in the ratio of change order costs to the original winning bid.

However, there is no longer evidence that work site elevation, the engineer's cost estimate, or the "top firm" identifier have any statistically significant effect. Moreover, there is evidence that the number of items on a project has a slightly negative relationship with the costliness of change orders on the project. Asphalt projects are associated with more costly change orders. Moreover, as indicated by the third through sixth columns, the evidence that top firms' superior information is associated with more costly change orders is very weak, and certainly much weaker

Table 4.4: Estimation results

Independent Variable	Number of Change Orders	
	Subsample	
	GMM	GMM IV
Log of Expected Duration	0.337***	0.349***
	(0.115)	(0.121)
Number of Items	0.006***	0.007***
	(0.002)	(0.002)
Log of Engineer Cost Estimate	0.069	0.030
	(0.075)	(0.072)
Elevation of Work Site	0.082**	0.083**
	(0.037)	(0.037)
Elevation of Work Site^2	-0.003*	-0.003*
	(0.002)	(0.002)
Winning Bid Deviation	0.424*	0.453*
	(0.249)	(0.268)
MLT	0.988	0.316
	(0.765)	(0.993)
MLT^2	0.138	0.926
	(0.817)	(1.020)
Top Firm	0.002	0.290
	(0.152)	(0.434)
Top Firm*MLT	2.860**	3.732**
	(1.229)	(1.509)
Top Firm*MLT^2	-12.871***	-13.397***
	(3.994)	(3.978)
Firm Experience	0.001	-0.002
	(0.002)	(0.003)
Expected Number of Bidders	0.007	0.007
	(0.021)	(0.021)
Unemployment Rate	0.057*	0.083**
	(0.030)	(0.033)
Log of Real Volume Projects	-0.782***	-0.925***
	(0.246)	(0.259)
Asphalt Project	0.050	0.004
	(0.224)	(0.257)
Bridge Project	-0.184	-0.221
	(0.216)	(0.250)
Seasonal Dummies	Yes	Yes
Observations	167	167

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

Table 4.5: Estimation results

Independent Variable	The Ratio of Change Orders Cost to the Winning Bid					
	Full Sample				Subsample	
	OLS	IV	OLS	IV	OLS	IV
Log of Expected Duration	0.030*	0.030*	0.030*	0.031*	0.033	0.033
	(0.016)	(0.016)	(0.016)	(0.016)	(0.023)	(0.024)
Number of Items	-0.001**	-0.001**	-0.001**	-0.001*	-0.001**	-0.001*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log of Engineer Cost Estimate	0.008	0.008	0.009	0.008	-0.008	-0.009
	(0.009)	(0.008)	(0.008)	(0.009)	(0.014)	(0.014)
Elevation of Work Site	-0.001	-0.001	-0.000	0.001	-0.007	-0.007
	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
Elevation of Work Site^2	-0.000	-0.000	-0.000	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Winning Bid Deviation	0.082**	0.082**	0.079**	0.064	0.066*	0.066*
	(0.037)	(0.037)	(0.039)	(0.042)	(0.037)	(0.037)
MLT	0.104*	0.103*	0.037	-0.027	-0.006	0.008
	(0.054)	(0.056)	(0.062)	(0.077)	(0.096)	(0.124)
MLT^2	-0.102	-0.101	-0.029	0.021	0.094	0.078
	(0.074)	(0.075)	(0.084)	(0.090)	(0.111)	(0.134)
Top Firm	0.013	0.015	-0.001	-0.010	-0.012	-0.035
	(0.014)	(0.026)	(0.017)	(0.028)	(0.023)	(0.039)
Top Firm*MLT	-	-	0.155	0.209*	0.136	0.122
	-	-	(0.105)	(0.119)	(0.151)	(0.179)
Top Firm*MLT^2	-	-	-0.106	0.332	-0.128	-0.118
	-	-	(0.412)	(0.370)	(0.592)	(0.585)
Firm Experience	0.000	0.000	0.000	0.000	0.000	0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Expected Number of Bidders	0.005**	0.005**	0.005**	0.004*	0.007**	0.007**
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
Unemployment Rate	0.010**	0.010**	0.010**	0.011**	0.011**	0.010**
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Log of Real Volume Projects	-0.050	-0.049	-0.056*	-0.060*	-0.059	-0.062
	(0.032)	(0.032)	(0.032)	(0.034)	(0.052)	(0.054)
Asphalt Project	0.030*	0.030*	0.028*	0.029*	0.011	0.013
	(0.017)	(0.017)	(0.017)	(0.017)	(0.026)	(0.026)
Bridge Project	0.013	0.013	0.011	0.011	-0.004	-0.005
	(0.018)	(0.019)	(0.018)	(0.019)	(0.021)	(0.022)
Seasonal Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	269	269	269	269	167	167
R^2	0.139	0.139	0.146	0.130	0.242	0.235

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

than the evidence that top firms' information is leading to simply a greater number of change orders. The R-squared on these regressions is quite low indicating that the model is accounting for about 14% of the variation in the costliness of change orders. The model performs a bit better in the subsample.

4.4 Conclusion

We find that uncertainty plays a major role in the occurrence of renegotiations. Uncertainty is associated with the complexity of a project and is measured by proxies, the most robust of which is the expected length of a project. Bidding behavior is also a powerful predictor of the likelihood of change orders and their relative importance. The larger the "bid premium" of the winning bid over the engineer's estimate, and larger disagreements among the bidders themselves, are related with a higher number of change orders and their greater cost relative to the total size of the project.

Moreover, there is evidence that the top firms in Vermont possess superior information on the likelihood of certain kinds of change orders, and incorporate that information into their bids. Given the level of industry concentration, it is important to note that we do not find significant evidence that top firms submit more costly change orders. These findings may permit agencies to better anticipate the likelihood of change orders, and perhaps mitigate their influence on project costs. Our results also suggest further lines of inquiry for economic research, especially to flesh out the sources of deviations between firms' bids.

Chapter 5

Conclusions

Ex post renegotiation frequently takes place in road construction contracts and there is often a significant increase in overall cost of procurement. The incidence of renegotiation affects firms' bidding strategies with negative effects on the efficiency of highway construction programs. This dissertation examines ex post renegotiation issued in the procurement auctions. The findings in each essay provide policy makers with suggestions that could increase the efficiency of budgetary planning.

The first essay is devoted to analyzing the effects of the renegotiation in Vermont highway contracts by using a structural auction approach. We examine how firm's bidding behavior is affected by its anticipation of ex post renegotiation. We develop a model that allows firms to predict quantity adjustments based on their historical probabilities and the necessity of renegotiation due to incomplete engineer's 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 markups of the bid. In the same projects, bidders lower their markups on items that are not renegotiated, creating a pattern of strategically skewed bids.

The second essay focuses on another type of renegotiations in which all participants typically have symmetric information on the need for the adjustment. We analyze the impact of renegotiation on firms' costs and markups, by focusing on contracts with unexpected tasks. We find that firms' costs are higher in projects with extra work while their markups are not statistically different with those in projects without such renegotiation. Finally, we could not find any evidence of bidders' strategic bidding behaviors that create their higher markups as often observed in projects with quantity adjustments.

The last essay provides an empirical analysis that examines the factors that associate with contract renegotiation on all highway and bridge construction projects undertaken in the state. This study suggests that project characteristics such as size, duration and location are valuable indicators of ex post renegotiation. The magnitude of disagreements among bidders could indicate the uncertainty about the true dimensions of the projects, and the firms' bidding behavior is also a useful predictor of change orders. We find weaker evidence that firms with superior information tend to renegotiate more frequently.

Bibliography

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

Anastasopoulos, P.C., Labi, S., Bhargava, A., Bordat, C., and Mannering, F.L., 2010. Frequency of Change Orders in Highway Construction Using Alternate Count-Data Modeling Methods, *Journal of Construction Engineering and Management*, 136 (8), 886–893.

Athey, S. and Haile, P.A., 2007. Nonparametric Approaches to Auctions, in Heckman, J. and Leamer, E. eds., *Handbook of Econometrics*, 6, (Amsterdam: North Holland) 3847–3965.

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

Athey, S., Levin, J., and Seira, E., 2011. Comparing Open and Sealed Bid Auctions: Evidence from Timber Auctions, *The Quarterly Journal of Economics*, 126 (1), 207–257.

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

Bajari, P. and Hortacsu, A., 2003. The Winner's Curse, Reserve Prices, and Endogenous Entry: Empirical Insights from eBay Auctions, *RAND Journal of Economics*, 34 (2), 329–355.

Bajari, P., Houghton, S., and Tadelis, S., 2014. Bidding for Incompete Contracts, *The American Economic Review*, 104 (4), 1288–1319.

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., 2001. Incentives versus Transaction Costs: A Theory of Procurement Contracts, *RAND Journal of Economics*, 32 (3), 387–407.

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.

Bordat, C., McCullouch, B., and Sinha, K., 2004. An Analysis of cost Overruns and Time Delays of INDOT Projects, *Technical Rep. Prepared for INDOT-FHWA-JTRP*, Indiana Department of Transportation, Indianapolis.

Bourn, J., 2001. Managing the Relationship to Secure a Successful Partnership in PFI Projects, London, National Audit Office.

Cameron, A.C. and Trivedi, P.K., 2005. *Microeconometrics: Methods and Applications*, Cambridge university press.

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.

Che, Y.K., 1993. Design Competition through Multidimensional Auctions, *RAND Journal of Economics*, 24 (4), 668–680.

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., Kosmopoulou, G., and Lamarche, C., 2009. The Effect of Information on the Bidding and Survival of Entrants in Procurement Auctions, *Journal of Public Economics*, 93 (1), 56–72.

De Silva, D.G., Dunne, T., and Kosmopoulou, G., 2003. An Empirical Analysis of Entrant and Incumbent Bidding in Road Construction Auctions, *The Journal of Industrial Economics*, 51 (3), 295–316.

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.

Decarolis, F., 2013. Comparing Public Procurement Auctions, *Working Paper*.

Donald, S.G. and Paarsch, H.J., 1993. Piecewise Pseudo-Maximum Likelihood Estimation in Empirical Models of Auctions, *International Economic Review*, 34 (1), 121–48.

Goeree, J.K. and Offerman, T., 2002. Efficiency in Auctions with Private and Common Values: An Experimental Study, *The American Economic Review*, 92 (3), 625–643.

Greene, W., 2009. Models for Count Data with Endogenous Participation, *Empirical Economics*, 36 (1), 133–173.

Grossman, S.J. and Hart, O.D., 1986. The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration, *The Journal of Political Economy*, 94 (4), 691–719.

Guasch, J.L., 2004. Granting and Renegotiating Infrastructure Concessions: Doing It Right, Washinton, D.C., World Bank.

Guasch, J.L., Laffont, J.J., and Straub, S., 2008. Renegotiation of Concession Contracts in Latin America: Evidence from the Water and Transport Sectors, *International Journal of Industrial Organization*, 26 (2), 421–442.

Guccio, C., Pignataro, G., and Rizzo, I., 2012. Determinants of Adaptation Costs in Procurement: An Empirical Estimation on Italian Public Works Contracts, *Applied Economics*, 44 (15), 1891–1909.

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.

Hart, O. and Holmstrom, B., 1987. The Theory of Contracts, in "Advances in Economic Theory: Fifth World Congress" (T. Bewley, Ed.), Cambridge University Press, Cambridge, UK.

Hart, O. and Moore, J., 1988. Incomplete Contracts and Renegotiation, *Econometrica*, 56 (4), 755–785.

Hart, O. and Moore, J., 1999. Foundations of Incomplete Contracts, *The Review of Economic Studies*, 66 (1), 115–138.

Hendricks, K. and Paarsch, H.J., 1995. A Survey of Recent Empirical Work concerning Auctions, *Canadian Journal of Economics*, 28 (2), 403–426.

Hendricks, K., Pinkse, J., and Porter, R.H., 2003. Empirical Implications of Equilibrium Bidding in First-Price, Symmetric, Common Value Auctions, *The Review of Economic Studies*, 70 (1), 115–145.

Hendricks, K. and Porter, R.H., 2007. An Empirical Perspective on Auctions, in M. Armstrong and R.H. Porter, eds., *Handbook of Industrial Organization*, 3, 2073–2143, New York: Elsevier.

Hilbe, J.M., 2011. *Negative Binomial Regression*, Cambridge University Press.

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.

Hsieh, T.y., Lu, S.t., and Wu, C.h., 2004. Statistical Analysis of Causes for Change Orders in Metropolitan Public Works, *International Journal of Project Management*, 22 (8), 679–686.

Iossa, E., Spagnolo, G., and Vellez, M., 2007. Contract Design in Public-Private Partnerships, Washinton, D.C., World Bank.

Kashap, S., 2004. Public Procurement as a Social, Economic and Political Policy, 3, 133–147.

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.

Krasnokutskaya, E. and Seim, K., 2011. Bid Preference Programs and Participation in Highway Procurement Auctions, *The American Economic Review*, 101 (6), 2653–2686.

Leffler, K.B., Rucker, R.R., and Mann, I.A., 2008. The Choice Among Sales Procedures: Auction vs. Negotiated Sales of Private Timber, Montana State University, Department of Agricultural Ecoomics and Economics.

Levin, D. and Smith, J.L., 1994. Equilibrium in Auctions with Entry, *American Economic Review*, 84 (3), 585–599.

Lewis, G. and Bajari, P., 2011. Procurement Contracting with Time Incentives: Theory and Evidence, *The Quarterly Journal of Economics*, 126 (3), 1173–1211.

Lewis, G. and Bajari, P., 2014. Moral Hazard, Incentive Contracts and Risk: Evidence from Procurement, forthcoming in *The Review of Economic Studies*.

Li, T., Perrigne, I., and Vuong, Q., 2002. Structural Estimation of the Affiliated Private Value Auction Model, *RAND Journal of Economics*, 33 (2), 171–193.

Marion, J., 2007. Are Bid Preferences Benign? The Effect of Small Business Subsidies in Highway Procurement Auctions, *Journal of Public Economics*, 91 (7), 1591–1624.

Maskin, E. and Tirole, J., 1999. Unforeseen Contingencies and Incomplete Contracts, *The Review of Economic Studies*, 66 (1), 83–114.

McAfee, R.P. and McMillan, J., 1987. Auctions and Bidding, *Journal of economic literature*, 25 (2), 699–738.

Milgrom, P.R. and Weber, R.J., 1982. A Theory of Auctions and Competitive Bidding, *Econometrica*, 50 (5), 1089–1122.

Oladapo, A., 2007. A Quantitative Assessment of the Cost and Time Impact of Variation Orders on Construction Projects, *Journal of Engineering, Design and Technology*, 5 (1), 35–48.

Oudot, J.M., 2006. Renegotiation of Defense Procurement Contracts, *Working Paper*, ATOM.

Schmitz, P.W., 2001. The Hold-Up Problem and Incomplete Contracts: A Survey of Recent Topics in Contract Theory, *Bulletin of Economic Research*, 53 (1), 1–17.

Segal, I., 1999. Complexity and Renegotiation: A Foundation for Incomplete Contracts, *The Review of Economic Studies*, 66 (1), 57–82.

Serag, E., Oloufa, A., Malone, L., and Radwan, E., 2010. Model for Quantifying the Impact of Change Orders on Project Cost for US Roadwork Construction, *Journal of Construction Engineering and Management*, 136 (9), 1015–1027.

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

Thai, K.V., 2001. Public Procurement Re-examined, *Journal of Public Procurement*, 1 (1), 9–50.

Wang, R., 2000. Bidding and Renegotiation in Procurement Auctions, *European Economic Review*, 44 (8), 1577–1597.

Williamson, O.E., 1976. Franchise Bidding for Natural Monopolies-in General and with Respect to CATV, *The Bell Journal of Economics*, 7 (1), 73–104.

Williamson, O.E., 1985. The Economic Intstitutions of Capitalism, New York, Free Press.

Windmeijer, F.A. and Santos Silva, J.M., 1997. Endogeneity in Count Data Models: An Application to Demand for Health Care, *Journal of applied econometrics*, 12 (3), 281–294.

Appendix 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.
Number of Change Orders	The number of change orders occurring in a project.
The Ratio of Change Orders Cost to the Winning Bid	It is the ratio of total change order amounts with quantity adjustments divided by winner's bid amounts.
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.
Number of Items	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).
Winning Bid Deviation	The proportional difference between the winning bid and the engineer cost estimates.
Money Left on the Table (MLT)	It is the proportional difference between the winning and the second lowest bid when there are multiple bidders. In the case of a single bidder, it is constructed as the proportional difference between the winning bidder and the engineering cost estimate.
Firm Experience	Firm experience is firm's number of years in business in the market. We measure it by counting years form establishment of the firm.
	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.

Appendix B

Technical Appendix

We assume that there are 4 bidders such as i, j, k and l to show how we derived equation (2.4). Equation (2.2) can be written as,

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

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

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

This equation can be written as,

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

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,

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

Simplifying we get equation (2.4):

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