博士論文

Three Essays on Public Procurement Auctions

（公共調達における入札制度に関する３本の論文）

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Chapter 1. Introduction

1 Analysis of Public Procurement

Public sector procurement makes up a substantial part of GDP: 10 – 20%.[1] Officials in public sectors are concerned not only with the procurement costs but also with the quality of work. As a result, *value for money*, which is a program about the effective use of government spending to improve the quality of work, has started to become common worldwide. Moreover, the government cares about the worsening of the quality of work due to the lack of new participants' experience in the case of relaxing the regulations of new entry. Cost overruns, which are prevalent in public-works procurement, are considered to be necessary to ensure safety for the execution of projects. Therefore, we empirically examine the effects of various types of systems used in public procurement in terms of price and quality. In particular, we focus on auction mechanisms in this dissertation.

In this dissertation, we adopt structural auction models and the program evaluation approach to quantitatively assess the effects of different auction mechanisms. The structural estimation approach is the method of estimating economic agents' parameters based on a theoretical model and simulating counterfactual scenarios which are absent in real-world. This approach enables us to compare between actual and counterfactual scenarios. In addition, the structural estimation approach averts Lucas critique which refers to the changes in preferences of economic agents due to policy changes and considers reduced-form estimations implausible. However, this approach tends to make strong assumptions on the theoretical model to estimate the parameters. In contrast to the structural estimation approach, the program evaluation approach enables us to assess the impacts of policy changes without imposing strong assumptions. We exploit exogenous sources of variation to identify the causal evidence on the impacts of policy changes. However, the program evaluation methods do not recover economic agent's structural parameters or simulate scenarios which are absent in real-world. Since the two estimation approaches have both advantages and disadvantages, we properly use the approaches depending on the situations.

This dissertation consists of three analyses. In Chapter 2, we examine the impacts of scoring auctions over (standard) price-only auctions through a structural auction model. In Chapter 3, we study the effects of relaxing entry regulations in public procurement auctions under a scoring design in terms of price and quality. For this empirical analysis, we exploit the methods of the program evaluation. In Chapter 4, we investigate the impacts of cost overruns on the quality of work and

[1] See http://www.cid.harvard.edu/cidtrade/issues/govpro.html

social welfare based on a structural estimation model. For our empirical analysis, we exploit a data set obtained from the record of the Ministry of Land, Infrastructure and Transportation (the MLIT) in Japan. The data set includes not only bids and the number of bidders but also the final payments determined after the completion of work and information on the quality of work reviewed at the time of completion.

2 Analysis of Scoring Auctions

Scoring auctions have recently started to become common worldwide. In a (standard) price-only auction, bidders submit price bids and the winner is the bidder with the lowest price bid among all the submitted price bids. In a scoring auction, bidders submit not only price bids but also quality bids as their bids. Prior to auction, the government announces a scoring rule which is the way to rank different bids. The quality bid consists of non-monetary attributes such as the time to completion. The government evaluates the bids and awards the contract to the bidder with the best combination (score) of the price bid and the quality bid. Che (1993) and Asker and Cantillon (2008) show that a scoring auction with a quasi-linear scoring rule gives incentive for bidders to improve the quality of work and welfare gain in comparison with price-only auctions. In spite of the prevalence of scoring auctions, the quantitative evaluations of scoring auctions in comparison with price-only auctions are limited with the exception of Lewis and Bajari (2011). Therefore, it is necessary to assess the impacts of scoring auctions over price-only auctions.

Chapter 2, which provides the quantitative evaluations of scoring auctions over price-only auctions, is titled as "The Impact of Scoring Auctions in Public Procurement: Empirical Analysis". We develop a structural model to quantify the benefits of scoring auctions over price-only auctions and estimate it using a dataset of price-only auctions including information on the quality of work in each contract. Our approach proposed in this analysis enables us to achieve the identification of various types of cost functions and the nonparametric identification of cost functions of quality levels when the sample size is large

In this analysis, we provide two sources of the potential benefits of implementing scoring auctions and quantify their effects. The first is the cost structures of improving the quality of work. The second is the government's uncertainty of the winning bidders' private information which is included in the cost functions. We compare large-scale and complex projects with small-scale and simple projects, for example, constructing a bridge and painting work on the road. Theoretical and empirical studies show that for the procurement of complex projects, price-only auctions may not work well due to the lack of contractors' expertise about construction practices. We assess the effects of scoring auctions for the two work projects which differ in the complexity and the size of a project.

We show that under scoring auctions, the quality of work improves by more than 10% and social welfare increases by about $2 - 7\%$. The impacts of scoring auctions are larger for bridge work compared with painting work. The government is faced with more uncertainty for bridge work.

3 Analysis of Effects of Relaxing Entry Regulations in Public Procurement under a Scoring Design

Entry regulations are common in many markets including public procurement. The government is concerned not only with the prices but also with the quality levels. In particular, in public-works procurement, officials in the government seem to believe that restricting participants in auctions can ensure ex post performance including the quality of work which is affected by both the uncertainty at the time of bidding and the moral hazard problem during construction. When the government relaxes entry regulations, many new firms enter a market. Large participation in the market can promote competition and reduce prices, but the new firms possibly supply poor-quality goods due to the lack of their experience. However, with the exception of Coviello, Guglielmo and Spagnolo (2014) and Decarolis (2014), there is still a scarcity of empirical research that considers ex post performance to quantify the impacts of the promotion of competition in public procurement. Therefore, it is important to quantify the impacts of relaxing entry regulations in terms of both price and quality in public-works procurement.

We show the quantitative evaluations of relaxing entry regulations under scoring auctions. Scoring auctions can give incentives for contractors to utilize their expertise and induce competition for not only the prices but also the designs. However, the government possibly manipulates the outcomes of scoring auctions through the manipulations of evaluating the quality bids submitted by bidders. In this case, relaxing entry regulations under scoring auctions comes to naught. However, in real-world, we do not know which effects strongly arise because of the scarcity of the empirical analysis of scoring auctions. Therefore, we provide empirical evidence on the effects of relaxing entry regulations under a scoring design.

Chapter 3 titled as "The Effects of Relaxing Entry Regulations on Price and Quality: Evidence from Public Procurement Auctions" provides quantitative evaluations for the benefits of open auctions over invited auctions under a scoring design to investigate the effects of relaxing entry regulations in terms of price and quality. In public-works procurement, invited auctions lead to repeated participation of particular firms to ensure the quality of work, while open auctions relax entry regulations to enhance competition and reduce price. We exploit a nationwide policy change and data including information on ex post performance in Japan. We show that under a scoring design, open auctions reduce cost overruns and delay in completion by more than 10% without worsening the quality of work.

4 Analysis of Impacts of Cost Overruns

In public-works procurement, cost overruns frequently arise because the winning bids are different from the final payments due to the presence of unanticipated productivity shocks during construction. However, with the exception of Bajari, Houghton and Tadelis (2014) and Miller (2014), there is still a scarcity of the structural model of bidding which incorporates the presence of the cost overrun and the execution of the project during construction into the model. Moreover, the empirical analysis of the moral hazard problem in public procurement is limited except for Lewis and Bajari (2014).

Chapter 4 titled as "Contractual Incompleteness and the Quality of Construction Works in Public-works Procurement: Empirical Analysis" provides a structural auction model which incorporates the cost overrun and the choice of the quality level by the contractor during construction. In the model, similar to McAfee and McMillan (1986), the government provides a linear payment schedule which consists of its bid and the cost overrun. In an auction, bidders submit bids and the bidder with the lowest bid receives the contract. The cost overrun arises during construction and is an incentive scheme to ensure the quality of work. This situation is close to the moral hazard because the cost overrun improves the contractor's effort level for the quality of work. We quantify the impacts of cost overruns on the quality of construction works and social welfare by using a data set including information on the final payment and the quality of work reviewed after the completion. In counterfactual experiments, we find that the welfare loss is 40% when cost overruns are reduced by 50%.

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Chapter 2. The Impact of Scoring Auctions in Public Procurement: Empirical Analysis

1 Introduction

Public sector procurement accounts for 13 – 20% of GDP on average worldwide.[2] In public procurement, the government is concerned not only with the procurement costs but also with the quality of construction works. Thus, scoring auctions have recently started to become common.[3] In a price-only auction, bidders submit prices and the winner is the bidder with the lowest price among all the submitted prices. In a scoring auction, the winner is the bidder with the best combination of the price and the quality score according to a pre-specified scoring rule. In this auction, bidders submit bids and design proposals. The government assigns quality scores by reviewing design proposals submitted by bidders and awards a contract to the bidder with the best score. Clearly, the performance of a scoring auction depends on its scoring rule. Asker and Cantillon (2008) theoretically show that under certain conditions, a scoring auction with a scoring rule which is linear in price is better than a price-only auction with the minimal quality standard with regard to social welfare and the government surplus in that the scoring auction with this rule gives incentives for bidders to improve the quality of work. In practice, however, there are various forms of transaction costs such as legal disputes and operational costs to review design proposals when the government implements scoring auctions. Therefore, it is important to evaluate the performance of scoring auctions in comparison with price-only auctions quantitatively.

In spite of the importance of the quantitative evaluations of scoring auctions, empirical analysis of scoring auctions is limited because available data of scoring auctions remains scarce. First, the number of observations in a data set may be small because governments have recently started to hold scoring auctions. In addition, there is still a scarcity of public procurement auctions where the program evaluation approaches, including the difference-in-difference and the regression discontinuity design, can be exploited. Second, the observed information in a data set of scoring auctions is typically single-dimensional (binding scores).[4] When we perform empirical analysis, we need to have separate information on prices and quality levels to interpret the estimation results. Moreover, in the case of binding scores, the structural model is unidentified due to the insufficient information because the information to be identified is multidimensional (e.g. the information on bidders' costs and the

[2]See http://www.oecd.org/gov/ethics/oecdjointlearningstudies.htm
[3]For scoring auctions held in the U.S and countries in the European Union, see Asker and Cantillon (2008).
[4]See Asker and Cantillon (2008).

functional forms of the costs in quality levels). Hence, separate information on prices and quality levels is required in each contract to make the observed information multidimensional. These restrictions on the data lead to the scarcity of the empirical analysis of scoring auctions.

In this paper, we develop a structural model of a price-only auction to simulate the equilibrium outcome of a scoring auction using a data set of price-only auctions. We formulate a first-price sealed bid auction with a secret reserve price where the cost function of each bidder is an increasing function of the quality of work. In this environment, the winning bidder does not have an incentive to improve the (minimum) quality level set by the government.

For our empirical analysis, we exploit a unique and rich data set of price-only auctions in public-works procurement in Japan. Our data set consists of the quality score of work reviewed after the completion, bids and the number of bidders. The quality score includes information on the performance of the work such as verticality and horizontality in foundation construction in addition to information on the completion time in each contract. Hence, we obtain multidimensional information to identify bidders' costs and the functional forms of the costs in quality levels because the data set includes not only the bids but also the quality levels.

We identify and estimate the cost functions of quality levels by using the structural estimation model and the data set. The functional form of the cost is unobservable, while the winning bidder's cost and the quality score of work are obtained in each contract based on the equilibrium relation between the winning bid and the winning bidders' cost derived from the structural model and the data set. In the structural model, the marginal cost of the cost function is assumed to be constant, so that the cost function is parameterized by the marginal cost of improving the quality of work and the fixed cost.[5] We write the marginal cost as θ_i and the fixed cost as α_i for firm i.[6] The marginal cost (θ_i) is private information and follows a distribution function $F_\theta(\cdot)$. To identify the cost function, we assume that the $2K$ observations in our data set consist of K firms which win two contracts located at different project sites. Moreover, we consider that the costs for firm i change only through the variation of the quality scores due to differences of project sites, while θ_i and α_i remain unchanged. In this environment, we obtain the marginal cost (θ_i) and the fixed cost (α_i) for firm i by solving simultaneous equations ($c_i = \theta_i Q + \alpha_i$ and $c_i^{'} = \theta_i Q' + \alpha_i$ where $i = 1, ..., K$) with two unknown values (θ_i and α_i).[7] To carry out this method, we consider two firms which have the closest estimated costs

[5]In this setting, we do not consider the presence of capacity constraints and the synergies of winning two contracts.

[6]In the Appendix, we provide a method to simulate the equilibrium outcome under a scoring auction without assuming the functional forms of the winning bidders' costs of the quality levels on the basis of the above approach when the sample size is large.

[7]We consider the following situation. A high-quality bridge is needed when the project site's condition is complex, while a low-quality bridge is required when the project site's condition is good. While project complexity and the quality levels are different, these two projects are performed under the same cost function for firm i because the sizes and

of the contracts as one firm. This is based on the idea that the two firms that participate in auctions of similar size tend to have similar cost functions.[8]

We provide two sources of potential benefits of implementing scoring auctions and quantify their effects. The first is the magnitude of the marginal cost of improving the quality of work. The second is the uncertainty of the winning bidders' private information included in the cost function from the government's perspective. In particular, we quantify the effects of scoring auctions to large-scale and complex projects, namely bridge work over small-scale and simple projects, namely painting work.[9] In the U.S and Italy, scoring auctions tend to be used to award large-scale and complex projects, while recently, in Japan, the auctions are applied to award not only large-scale and complex projects but also small-scale and simple projects such as painting work.[10] Goldberg (1977) and Bajari, McMillan and Tadelis (2009) suggest that for complex projects, price-only auctions may not perform well because of the lack of expertise by contractors who have knowledge about construction practices. In contrast to price-only auctions, scoring auctions may work well in the procurement of complex projects because they provide incentives for contractors to exploit their expertise and improve the quality levels. Since we expect that bridge and painting work projects differ in cost structures (i.e. the marginal costs of improving the quality levels and the fixed costs), we examine the cost functions of quality levels. Moreover, we investigate government's technical uncertainty for the two work projects. In fact, the government is faced with technical uncertainty about construction practices when awarding complex projects. Hence, we quantify the marginal benefits of scoring auctions over price-only auctions for the two specific work projects which are expected to differ in the cost structures and project complexity.

The estimation results show that the variable cost (θQ) accounts for the large proportion of the estimated cost of a project for both work projects. In addition, the results also suggest that bridge work and painting work differ in cost structures (i.e. the marginal costs of improving the quality levels and the fixed costs). The results of cost functions indicate that the marginal cost is smaller for bridge work compared with painting work and the fixed cost is larger for bridge work. The estimation results also suggest that the government faces more uncertainty of the winning bidders' private information for bridge work because the variance of the marginal cost is basically larger for bridge work relative to painting work.

In counterfactual experiments, we simulate the quality of work and social welfare under the scoring auction demonstrated by Che (1993). We convert the quality score of work into a monetary value

complexity of the projects are considered to be similar.

[8]In the market for our analysis, this idea is realistic due to the presence of the small business set-aside program where small (large) firms compete with small (large) firms when a small (large)-scale contract is awarded.

[9]Bridge work is more complex than painting work because the project size per contract is larger for bridge work and the number of categories to complete a project is also larger for bridge work.

[10]See Lewis and Bajari (2011) and Decarolis (2014) for the cases of the U.S and Italy.

by using the quality score of work and the reserve price observed in the data set. We consider the reserve price as the government's valuation of a contract because as shown in Elyakime, Laffont, Loisel and Vuong (1994), the government's valuation of a contract is equal to the reserve price due to the characteristic of a first-price sealed bid auction with a secret reserve price. Using the quality score of work, the valuation of a contract for the government which is the demand side of a contract and the cost function of the winning bidder which is the supply side, we set a scoring rule in the scoring auction and derive social welfare under price-only and scoring auctions.

The counterfactual results show that the impacts of social welfare and the quality of work under scoring auctions are larger compared with price-only auctions for the two types of work projects. When scoring auctions are used to award bridge work projects, the welfare gain is about 5.5% (JPY 2.5 million (approximately USD 25 thousand)) and the quality of work rises by 14% on average compared with price-only auctions. With regard to painting work, under the scoring auctions, the welfare gain rises by about 3.6% (JPY 0.39 million) and the quality of work increases by 11% relative to the price-only auctions. These results suggest that the differences of the performance of scoring auctions are consistent with the implications suggested by Goldberg (1977) and Bajari, McMillan and Tadelis (2009) because for complex work projects, scoring auctions perform better than price-only auctions.

To our knowledge, this is the first paper that develops a structural estimation model to quantify the benefit of scoring auctions over price-only auctions.[11] From the information we have, Lewis and Bajari (2011) is the only empirical study that compares scoring and price-only auctions. They use OLS to quantify the impacts of scoring auctions with A+B design (A: a monetary bid and B: a total number of days to deliver the contract) over price-only auctions using a data set which consists of price-only and scoring auctions. Our structural estimation method allows us to quantify the benefit of a scoring auction over a price-only auction without using scoring auctions' data. Our identification strategy achieves the identification of various types of cost functions and the nonparametric identification of cost functions of quality levels when the sample size is large.[12]

This paper also contributes to the literature on scoring auctions. In scoring auction theory, Che (1993) and Asker and Cantillon (2008) analyze the equilibrium outcome of a scoring auction with a commonly used scoring rule. Lewis and Bajari (2011) focus on large-scale and complex projects to compare scoring and price-only auctions. In this paper, we quantify the impacts of scoring auctions

[11] Bajari, Houghton and Tadelis (2014) structurally analyze an auction with multidimensional attributes to estimate adaptation costs based on the method of Che (1993) and Asker and Cantillon (2008).

[12] Our identification methods may be applicable to the investigations into a difference between two scoring auctions with different scoring rules utilizing a data set obtained under just one type of scoring auction.

for two specific work projects which differ in the cost structures and technical uncertainty.[13] Goldberg (1977) and Bajari, McMillan and Tadelis (2009) suggest that to award complex projects, methods for giving incentives for contractors to exploit their expertise are attractive for the buyer. However, their implication has not been examined in the context of scoring auctions with the exception of this paper. This paper brings notices to these points because there have been no empirical or theoretical studies which discuss when the use of scoring auctions is more beneficial.

This paper is also related to the structural analysis of procurement auctions (Brannman and Froeb (2000), Hong and Shum (2002), Bajari and Ye (2003), Jofre-Bonet and Pessendorfer (2003), Li and Ji (2006), Flambard and Perrigne (2006), Marion (2007), Li and Zheng (2009), Nakabayashi (2009), Krasnokutskaya (2011), Krasnokutskaya and Seim (2012), Somaini (2012), Balat (2012), Decarolis (2013), Bajari, Houghton and Tadelis (2014), Bhattacharya, Roberts and Sweeting (2014), Groeger (2014), Miller (2014)).

The paper is organized as follows. Section 2 presents the auction data, summary statistics and some preliminary analysis. Section 3 and 4 describe our price-only auction model and identification methods. Section 5 provides the estimation methods. Section 6 is devoted to a presentation of estimation results and the counterfactual simulations. Section 7 concludes this paper. The Appendix shows the definition of variables and the identification of the structural model.

2 Competitive Bidding, Data and Preliminary Analysis

2.1 Procurement Procedure

This section shows an overview of the procurement system of public-work projects. We concentrate on procurement auctions under the Ministry of Land Infrastructure and Transportation (the MLIT) in Japan. The MLIT is in charge of nationwide public-works procurement. In the MLIT, there are eight regional bureaus (Tohoku, Hokuriku, Kanto, Chubu, Kinki, Chugoku, Shikoku and Kyushu) and Hokkaido regional development bureau. Each regional bureau is the local agency of the MLIT and has its own territory. The regional bureaus hold procurement auctions in their territories and solicit bids from prospective bidders.

The public procurement takes place as displayed in Figure 1. In the phase of designing a contract, the government presents the specification, the plan, the reserve price, the appraisal value and the

[13] Hong and Shum (2002) and De Silva, Dunne, Kankanamge and Kosmopoulou (2008) compare different types of work projects (bridge work and paving work). They focus on the differences of the magnitudes of common cost uncertainty between different types of work projects, while this paper analyzes the differences of cost structures (i.e. the marginal costs of improving the quality levels and the fixed costs for different work projects) and the government's technical uncertainty between different work projects.

length of the contract in days (the engineer's days estimate). The reserve price is constructed by engineers in the government based on the specification and plan of the contract. The appraisal value is a minimum price to avoid excessive competition in an auction. The appraisal value is constructed as about 70% of the value of the reserve price.

Bidder qualification processes are implemented prior to auction. There are two methods of qualifying bidders, namely invited and open auctions. In an invited auction, only firms chosen by the government are given contract information and are allowed to submit bids. There are two categories for the invited auction. For the first category, there are not definite criteria to choose bidders. With regard to the second category, the government chooses firms based on information including their financial conditions. For both categories, the government chooses about 10 firms in an auction. In an open auction, the government broadly advertises the description of a contract and any firms which satisfy the minimum requirements including financial conditions and technical requirements set by the government can voluntarily submit bids. Open auctions tend to be used to award large-scale and complex projects.

A small business set-aside program is implemented in the market for bridge work projects. In this program, the government allows small firms to submit bids and exclude large firms in the auction when it awards small-scale contracts. A rating system determines the contract size where a firm is allowed to submit its bid. The rating system evaluates the firm's financial condition, the number of engineers employed and the firm's construction revenue. When the government qualify a firm as a small (large) firm through the rating system, the firm is allowed to participate in an auction for a small (large)-scale contract. The government updates the information every one or two years. Table 1 indicates that firms with rank A or B (C or D), which are qualified as large (small) firms, are basically allowed to participate in auctions for rank A or B (C or D) where large (small)-scale contracts are awarded.[14] Table 1 presents that for auctions with rank C and D, about 95% of firms participating in the auctions are qualified as rank C and D. With regard to auctions with rank A and B, about 90% of firms participating in the auctions are qualified as rank A and B.

After qualifying bidders, the government uses a price-only auction (a first-price sealed-bid auction) with a secret reserve price to award a contract. If the lowest bid is lower than the reserve price, the government awards the contract to the bidder with the lowest bid. The reserve prices are disclosed after the bids are opened, while they are kept undisclosed at the time of bidding.

In each contract, engineers in the government review the quality level and check whether the

[14]In rank A, contracts with a reserve price above JPY 730 million are awarded, in rank B, contracts with a reserve price between JPY 300 and 730 million are awarded, in rank C, contracts between JPY 60 and 300 million are awarded and in rank D, contracts below JPY 60 million are awarded.

construction is performed according to the specification and plan during construction and at the time of completion.[15] After the completion of work, they assign the quality score of work based on the evaluations of the quality of work. The quality score consists of the performance of work, the quality of work, the level of completed work, the level of execution management, the system of the execution of work, the safety management, the schedule control (up to these factors, more than 70 % of the score is constituted), the consideration to the environment around the project site, the ingenuity for the execution of work, the ability of engineers, the technology level used to perform work and the legal compliance. In particular, the consideration to the environment around the project site, the ingenuity for the execution of work and the technology level used to perform work are considered when the contractor deals with some complex conditions due to the natural environment, the living environment and the geological condition at the project site. The quality score of work is evaluated on a range of 0 to 100 points. The criteria of evaluating the quality score of work is the same between the two work projects. The government imposes penalties including nomination stops in auctions and re-construction to the contractor's cost when the quality level after the completion of work is too low.

2.2 Data and Summary Statistics

We have the data of public-works procurement held by the eight regional bureaus from April 2005 to March 2007. In the period for our analysis, the eight regional bureaus in the MLIT awarded 23396 contracts in total. The 23396 contracts includes electric insulation work, machinery equipment, the construction of roads, road painting, bridge construction and maintenance. We choose price-only auctions from April 2005 to March, 2007.

For our empirical investigations, we focus on two types of work projects which differ in cost structures, the size of a project and project complexity: bridge work and painting work. Bridge work is composed of upper structure of steel bridges, prestressed concrete bridges, bridge construction works and bridge maintenance and rehabilitation. Panting work consists of mainly painting carriageway marking and painting work to prevent the rust of bridges. Bridge work generally requires more complex tasks compared with painting work according to a construction technical document for public-work projects presented by the MLIT. The size of a project is basically larger for bridge work compared with painting work. The number of categories to complete a project is also generally larger for bridge work. Hence, we expect that the cost structure to complete a project is different between the two work projects and the government's uncertainty about a project is larger for bridge work.

From the data set, for each auction, we have information on the reserve price of a project, the

[15]For simple projects, they review the quality levels only after the completion of work.

contract location of a project, the contractual and actual time to complete a project, a description of a project (e.g., bridge work, painting work. etc.), individual bids and their identity, the winning bid, the final payment, the identity of firms invited by the government in an invited auction, the identity of firms which show their interests for a project in an open auction and the quality score of work reviewed after the completion.

In this paper, we define potential bidders in an invited auction as firms which are chosen by the government, while we define actual bidders as firms which eventually submit bids. Potential bidders in an open auction are treated as firms which show their interests for a certain contract and satisfy the minimum requirements set by the government, while actual bidders are treated as firms which eventually submit bids. The number of potential bidders and the number of (actual) bidders are sometimes different because firms which find more profitable contracts do not submit bids.

Table 2 shows some summary statistics of the auction data. Our data set provides 776 auctions for bridge work and 280 auctions for painting work. In the data set, invited auctions are dominant. For painting work, the first category of invited auctions is dominant, while for bridge work, the second category of invited auctions accounts for the large proportion of the data. The average of reserve prices is about JPY 120 million (approximately USD 1.20 million) for bridge work and is about JPY 28 million (about USD 0.28 million) for painting work. The relationship between the number of potential bidders and the number of actual bidder is interesting. For bridge work, the number of potential bidders is very close to the number of actual bidders because the average number of potential bidders is 9.1 and the average number of actual bidders is 8.1. For painting work, the same tendency is observed because the average number of potential bidders is 11.2 and the average number of actual bidders is 10.7. These results present that about 90% or more of potential bidders eventually submit their bids. In addition, for both work projects, the number of potential bidders and the number of (actual) bidders are close to 10 which is the number of bidders selected by the government in invited auctions. With regard to the quality score of work, the average of the quality scores for bridge work is about 73.6 and about 72.1 for painting work. While the average of the difference between those two values is 1.5, the difference is significantly different from 0. Observing the standard deviation of the quality score of work, we find that the quality scores vary across contracts.

We model bidders to be symmetric after examining the data. In the entire period for our analysis, the top share firm wins less than 3% of the total contracts for bridge work and 1.5% of the total contracts for painting work. For both of those works, more than 95% of firms win less than 1% of the total contracts. In the period of our analysis, for painting work, about 65% of firms win auctions only once and for bridge work, about 52% of firms receive contracts only once. Based on the evidence, we consider that there are only fringe bidders and the presence of capacity constraint is not significant in the market for our analysis. Moreover, in the procurement auctions, small-scale projects are set aside for small firms. This means that small (large)-scale firms compete with each other when a small (large) -scale project is awarded. For bridge work, the small business set-aside program is applied to about 60% of the entire auctions for our analysis. For painting work, there are no extremely gigantic firms in the data set. Hence, we consider that bidders are basically symmetric in the procurement auctions for our analysis.

2.3 The definition of Variables

There are four auction-level characteristics: the log of the reserve price, the log of the contract length and the number of potential bidders (or the log of the number of potential bidders). The reserve price and the contract length control for differences in contract sizes which change across auctions. The number of potential bidders controls for the differences in the level of competition across auctions.

We introduce four variables to control for differences in geological conditions across project sites because bridge work projects are generally influenced by geological conditions at the project sites. For example, a high-quality bridge is required when the project site's ground is bad, while a low-quality (standard) bridge is needed when the project site condition is good. We construct the variables of the conditions of surface ground, faults, landslides and liquefaction around the project sites. The Appendix shows the definitions of these variables.

We present two variables to control for meteorological conditions that change across project sites. We introduce the variables of the amount of rainfall and the minimum temperature at the project site. For bridge work projects, the large amount of rainfall worsens the condition of surface ground at the project site through underground water. These factors also have influence on the condition of concrete for bridge work projects. The minimum temperature and humidity also affect the performance of the work for painting work projects through the speed of drying and dust in air. We describe the detailed information on the construction of the variables in the Appendix.

We bring two variables to control for differences in business environments around the project sites: the construction materials prices, the oil price and the income level around the project site. The variable of the construction materials prices is used to estimate the model for bridge work. We use the movement of the oil price to estimate the model for painting work. In addition, we have 11 monthly dummy variables. The Appendix shows the definitions of these variables.

2.4 Reduced-Form Analysis

We empirically assess the effects of competition among bidders by using regression analysis. The estimation model at auction a is given by:

$$Y_a = \beta_1 + \beta_2 N_a + X_a'\beta_3 + \epsilon_a$$

The dependent variable Y_a is the log of the winning bid or the relative winning bid. N_a is the number of potential bidders (or the log of the number of potential bidders). The coefficient on N_a, β_2 is the main interest of this estimation which measures the effect of competition in auctions. X_a' consists of the auction-level variables, the variables measuring the geological conditions, the variables capturing meteorological conditions, the variables representing the economic environments and monthly dummies. With regard to painting work, we do not include the variables of geological conditions in the estimations.

Tables 3 and 4 show that for both types of work projects, the potential number of bidders has significant negative effects on the winning bids across all the estimation models. Based on the estimation results, we consider that auctions are competitive for both work projects.

We then empirically examine the relationship between the quality score of work and the geological and meteorological conditions. We expect that the quality score of work is influenced by those conditions because they can affect technical requirements, expertise for the execution of the work, the schedule control and the performance of the work. Using regression analyses, we show which factors influence the quality score of work. The estimation model at auction a is given by:

$$Y_a = \beta_1 + G_a'\beta_2 + M_a'\beta_3 + X_a'\beta_4 + \epsilon_a$$

The dependent variable Y_a is the quality score of work. G_a' consists of four variables that measure the geological conditions. M_a' contains two variables measuring meteorological conditions. The coefficients on G_a' and M_a', β_2 and β_3, are the main interests of this estimation model. X_a' is composed of the other explanatory variables.

The estimation results are displayed in Table 5. We find that the quality score of work is significantly affected by several factors. We observe that the quality score of work increases in the contract size for the two work projects. For painting work, the temperature condition affects significant positive effect on the quality score of work. The precipitation condition also has significantly negative effect on the quality score of work. The contractor exercises ingenuity to ensure the quality of work under a dry condition because they are faced with the suppression of dust to prevent traffic accidents due to low visibility. As Table 5 shows, with regard to bridge work, the meteorological conditions have significantly positive effects on the quality score of work, while the variables for the geological conditions are not statistically significant. The large amount of rainfall worsens geological conditions at the project site due to the presence of a large quantity of groundwater. Hence, the coefficient of the amount of rainfall means that the contractor needs to exploit expertise to ensure the quality of work at the project site.

3 Theoretical Model

3.1 Equilibrium Bidding Behavior in a Price-Only Auction

In this section, we propose a theoretical model to analyze the auction data. We modify a first price sealed-bid auction (FPA) model with a secret reserve price by incorporating the choice of the quality level at the time of bidding into the model.

We consider an auction model with N risk-neutral and symmetric bidders. Prior to auction, each firm draws her cost parameter θ from an independent and identical distribution $F_\theta(\cdot)$ defined on $[\underline{\theta}, \bar{\theta}]$. The corresponding density function is denoted by $f_\theta(\cdot)$. Each firm submits a bid b in an auction. The winning bid is denoted by w. $F_\theta(\cdot)$ and N are assumed to be common knowledge.

In the model, each firm chooses the quality of work (Q) at the time of bidding. The quality level is assumed to be one dimension. We also assume that there is no uncertainty about the quality level because the quality level determined at the time of bidding is achieved at the time of completion due to the review of the quality of work during construction and after the completion. The firm's cost function $C(Q, \theta)$ is assumed to be $C_\theta(Q, \theta) > 0$ and $C_Q(Q, \theta) > 0$.

We proceed to the analysis of the optimization problem for bidders. The method of solving the optimization problem is similar to Che (1993), Asker and Cantillon (2008) and Bajari, Houghton and Tadelis (2014). First, fixing bid (b), each bidder determines a quality level. Second, given the quality level, the equilibrium bid for the bidder is derived. This means that in equilibrium, the quality level is separately derived from the bid. The quality level is determined as follows:

$$\max_Q \; -C(Q, \theta) \qquad \text{where} \qquad Q \in [\underline{Q}, \bar{Q}] \Leftrightarrow \; Q^* = \underline{Q} \tag{1}$$

Putting $Q^* = \underline{Q}$ into the cost function, the optimization problem is rewritten as the problem of choosing b given $C(\underline{Q}, \theta)$. Hence, the expected profit function for each firm is written by:

$$\pi(b, \underline{Q}|\theta) = [b + E(P) - C(\underline{Q}, \theta)]\text{Prob}(\text{win}|b, \underline{Q})$$

In the expected profit function, we introduce the extra payment that is the difference between the winning bid and the final payment. We denote the extra payment as P. Since each firm faces the uncertainty of the extra payment P at the time of bidding, this variable is represented as an expected value, namely $E(P)$. We consider that the extra payment corresponds with the movement of construction materials prices. The expected value of the extra payment is assumed to be symmetric and common knowledge.

We consider a first price auction with a secret reserve price. The reserve price is denoted by r that is drawn from a distribution $H(\cdot|\underline{Q})$ with the density $h(\cdot|\underline{Q})$ because we consider that the quality score and the reserve price are constructed based on the specification designated by the government and $\underline{Q}$ is assumed to be the quality level based on the specification set by the government in the stage of designing the contract. r and θ are assumed to be independent conditional on $\underline{Q}$. $H(\cdot|\underline{Q})$ is also assumed to be common knowledge.

We assume that bidders develop their bidding strategies according to $C(\underline{Q}, \theta) = c$ with a cumulative distribution $F(\cdot|\underline{Q})$. We introduce the strictly increasing equilibrium bidding strategy $\sigma(\cdot)$ and set $b = \sigma(c)$. We then derive the equilibrium bidding strategy in the same method as Elyakime et al. (1994) and Li and Perrigne (2003). The winning probability is given by:

$$\text{Prob}(\text{win}|b, \underline{Q}) = (1 - F(\sigma^{-1}(b|\underline{Q})))^{N-1}(1 - H(b|\underline{Q}))$$

Therefore, the expected profit function for each firm is given by:

$$\pi(b, \underline{Q}|\theta) = [b + E(P) - c](1 - F(\sigma^{-1}(b)|\underline{Q}))^{N-1}(1 - H(b|\underline{Q}))$$

This bidding environment is almost the same as a first price sealed bid auction with a secret reserve price presented by Elyakime et al. (1994) and Li and Perrigne (2003). Each bidder maximizes the expected profit function $\pi(b, \underline{Q}|\theta)$ with respect to b. Hence, the unique symmetric equilibrium bidding strategies $\sigma(\cdot)$ satisfies the following equation:

$$\sigma^{'}(c)(1-F(c|\underline{Q}))(1-H(\sigma(c)|\underline{Q})) = (\sigma(c)+E(P)-c)[(N-1)f(c|\underline{Q})(1-H(\sigma(c)|\underline{Q}))+(1-F(c|\underline{Q}))h(\sigma(c)|\underline{Q})\sigma^{'}(c)] \tag{2}$$

where $c = C(\underline{Q}, \theta)$. The distribution function and the corresponding density function of the reserve prices are defined as the same support as $F(\cdot|\underline{Q})$. The equilibrium strategy $\sigma(\cdot)$ solves the above differential equation subject to the boundary condition $\underline{c} = \sigma(\underline{c})$.

As (1) shows, contractors set the quality level as $Q^* = \underline{Q}$ in equilibrium. Hence, contractors perform projects which are set as the minimum quality standards because price-only auctions do not give incentives for contractors to improve the quality of construction works. We can interpret that in this environment, contractors perform the projects according to the specifications determined by the government in the phase of designing contracts. We consider that the contractors do not have incentives to choose quality levels which are less than the quality levels set by the government because of the presence of the penalties for low-quality work. Hence, $Q^* = \underline{Q}$ can be regarded as the quality level based on the specification designated by the government in the stage of designing the contract.

The specification of the expected profit function is consistent with real-world public procurement auctions as described before. This formulation is analogous to that of Bajari, Houghton and Tadelis (2014) in that we allow the presence of the extra payment in the expected profit function. Moreover, in this model, we do not consider the uncertainty of the number of bidders because we confirm that the number of potential bidders and that of actual bidders are close to 10 which is the number of bidders chosen by the government in an invited auction. We also find that about 90% or more of potential bidders selected by the government eventually submit bids from the summary statistics.

We consider the government's optimization problem. Let the government be risk neutral. The government's valuation of a contract is denoted by v_B drawn from a distribution $F_B(\cdot|\underline{Q})$. Under a first price sealed bid auction with a secret reserve price, the government sets the reserve price r to maximize her expected surplus: $E[(v_B - E(P) - W)1(W \leq r)]$ where $W = \sigma(c_{1:N})$. The government's optimal strategy is truth telling and $v_B - E(P) = r$. The method of proof is the same as Elyakime et al. (1994).

3.2 Equilibrium Outcomes under A Scoring Auction: the Counterfactual Scenario

We describe the model of the scoring auction introduced by Che (1993) to carry out counterfactual analysis. A scoring auction with a quasi-linear scoring rule is typically used in the U.S.[16] In Japan, the scoring auction with this rule is used in nine prefectures including Iwate prefecture and Miyagi prefecture.[17]

In the scoring auction, each bidder offers quality-price combinations (b, Q). A scoring rule announced by the government prior to auction is given by $S(b, Q) = V(Q) - b$ where $V'(Q) > 0$ and

[16]For information on A+B design in the U.S., see Asker and Cantillon (2008).

[17]For this information, see www.nilim.go.jp/lab/peg/siryou/sougou/iinkai/sankou8-2_siryou.pdf

$V''(Q) < 0$. $V(Q)$ is the value of a contract for the government at a quality level Q.

We analyze the equilibrium outcome under the scoring auction. Each bidder chooses their price-quality combination (b, Q) that maximize his or her profit conditional on winning:

$$\max_{(b,Q)} b - C(Q,\theta) \text{ sub to } s = V(Q) - b$$

Since the scoring rule is quasi-linear, the optimal quality $Q_O(\theta)$ is derived as follows:

$$Q_O(\theta) \in \max_Q V(Q) - C(Q,\theta) \Leftrightarrow V^{'}(Q_O) - C_Q(Q_O(\theta),\theta) = 0$$

where $V(Q) - C(Q,\theta)$ is assumed to have a unique maximum solution in Q over $[\underline{Q}, \bar{Q}]$ for all $\theta \in [\underline{\theta}, \bar{\theta}]$. The optimal quality is determined independently from the choice of score s. $V(Q(\theta)) - C(Q, \theta(\theta))$ is social welfare.

When the scoring rule is assumed to be $S(b, Q) = a \log Q - b$ where a is a parameter, the optimal quality level under the scoring auction is given by:

$$Q_O(\theta) \in \frac{a}{Q} - \theta = 0 \Leftrightarrow Q_O(\theta) = \frac{a}{\theta}$$

Substituting $Q_O(\theta) = \frac{a}{\theta}$ into $V(Q) - C(Q,\theta)$, we obtain social welfare $(a \log a - a \log \theta - (a + \alpha))$ under the scoring rule. $Q_O(\theta)$ and $V(Q_O(\theta)) - C(Q_O(\theta),\theta)$ are decreasing in the marginal cost (θ). Hence, the smaller the marginal cost is, the larger the quality level and social welfare are if the parameter a is fixed.

4 Identification of the Structural Model

We provide the identification of the structural model by using information on the winning bid w, the quality of work and the number of bidders N included in the data set. The structural model is $[F_\theta(\theta), C(Q,\theta)]$.

In this paper, the quality score is assumed to be the quality level based on the specification and plan determined at the phase of designing the contract, while it is the quality of work reviewed after the completion. We consider that the assumption is realistic because of the presence of reviews during construction and after the completion in addition to the penalties for low quality work. The assumption allows us to consider $\underline{Q}$ in the model as the quality score of work observed in the data set. Hence, we observe the quality level besides the winning bid and the number of bidders in each auction. We note that the quality score of work is observed only for the winning bidder in each contract.

The equilibrium inverse bidding function is denoted by $\xi(\cdot)$. By using the change of variables as in Guerre, Perrigne and Vuong (2000) and the characteristic of the order statistics, we write the FOC (2) as follows:

$$c_{1:N} = w + E(P) - \frac{(1 - G_W(w|\underline{Q}))(1 - H(w|\underline{Q}))}{\frac{N-1}{N} g_W(w|\underline{Q})(1 - H(w|\underline{Q})) + (1 - G_W(w|\underline{Q}))h(w|\underline{Q})} = \xi(w) \tag{3}$$

where $c_{1:N} \equiv C(\underline{Q}, \theta_{1:N}))$ is the winning bidder's cost, $G_W(\cdot|\underline{Q})$ is the distribution function of the winning bids and $g_W(\cdot|\underline{Q})$ is the corresponding density function. $H(\cdot|\underline{Q})$ is the distribution of the reserve prices and $h(\cdot|\underline{Q})$ is the corresponding density function. In this situation, the functional form of the cost is unobservable, while the winning bidder's cost and the quality score of work are observable in each auction based on the equilibrium relation between w and $c_{1:N}$ derived from the auction model and the data set.

For our empirical analysis, we assume $C(Q, \theta) = \theta Q + \alpha$ because we are faced with a restriction on the number of observations for the estimations.[18] The marginal cost (θ) is private information for each bidder. We also assume that the distribution of the marginal cost ($\theta_{1:N}$) and the fixed cost (α) are independent of the quality score of work ($\underline{Q}$). The key of our identification approach is to utilize a property that the winning bidders' costs ($c_{1:N}$) vary with quality scores ($\underline{Q}$), while the marginal cost ($\theta_{1:N}$) and the fixed cost (α) do not.

We consider that the $2K$ observations in our data set consist of $i = 1, ..., K$ firms which win two contracts located at different project sites. For the simplification of notations, we denote $c_{1:N}$ as c and $\theta_{1:N}$ as θ. Thus, we have two observations $(\underline{Q}, c_i)$ and $(\underline{Q}', c'_i)$ for firm i, where $c_i = C(\underline{Q}, \theta_i)$ and $c'_i = C(\underline{Q}', \theta_i)$. Moreover, we consider that firm i's θ_i and α_i remain unchanged, while the quality score of work $\underline{Q}$ changes across contracts $((\underline{Q} < \underline{Q}'))$. Hence, firm i's costs (c_i) vary across contracts due to the variation of the quality scores ($\underline{Q}$) because θ_i and α_i are unchanged. This environment allows us to obtain θ_i and α_i across firm $i = 1, .., K$ by solving the following simultaneous equation:

$$c_i = \theta_i \underline{Q} + \alpha_i \qquad \text{and} \qquad c'_i = \theta_i \underline{Q}' + \alpha_i$$

[18]The functional form of $C(Q, \theta) = \theta Q + \alpha$ is used in Asker and Cantillon (2010). When we do not consider the fixed cost (α), the identification of θ is straightforward. The functional form of $C(Q, \theta) = \theta Q$ is considered in theoretical literature on scoring auctions including Che (1993) and Celentani and Ganuza (2002). When engineers in the construction industry discuss the cost functions of quality levels, it is assumed that the functional form of the cost is linear in the quality level. See The Committee of an Examination for the License of Civil Engineering (1997).

When the marginal costs θ_i vary across firm $i = 1, ..., K$ and are assumed to follow a distribution function, we observe the distribution function of the marginal cost ($F_{\theta_{1:N}}(\cdot)$). Hence, we identify $F_{\theta_{1:N}}(\cdot)$ and α_i across $i = 1, ..., K$.

In this environment, we consider that the quality scores ($\underline{Q}$) vary across contracts thorough differences of geological, meteorological and some other conditions due to the variation of contract locations. As displayed in the previous section, we observe that the quality score of work is affected by geological and meteorological conditions that change across project sites. When the contractor is faced with the complex conditions for the suppression of dust in a drying environment (painting work) and soft ground conditions through underground water (bridge work), the quality score of work ($\underline{Q}$) and the cost to complete the project (c_i) will increase. Hence, we consider the following situation: high-quality, and hence costly work is required when the project site's condition is complex, while low-quality, and hence ordinary work is needed when the project site's condition is good.

When the two projects for $\underline{Q}$ and $\underline{Q}'$ are similar contract sizes and types, firm i can perform these projects under the same cost function. Hence, the difference between c_i and c'_i arises for firm i with θ_i and α_i based on only the variation of $\underline{Q}$ through the differences in complexity of projects. Moreover, invited auctions are dominant in the market for our analysis. In invited auctions, bidders cannot voluntarily submit bids because the government selects bidders in the auctions. In particular, for painting work, the government tends to choose bidders randomly because of no definite criteria for the selection of bidders. Hence, the marginal cost ($\theta_{1:N}$) and the fixed cost (α) are considered to be independent of the quality score of work ($\underline{Q}$) because in the auctions for our analysis, we can consider that the government randomly determines auctions where bidders submit bids.

This approach leads to the identification of a number of monotonic cost functions with two unknown values including $\theta Q^2 + \alpha$ and $\theta \exp Q + \alpha$. If the sample size is large, our identification strategy allows us to obtain θ_i and $\alpha_s > 0$ ($s = 0, ..., S$) for general polynomial forms of cost functions including $\theta Q^S + \alpha_{S-1} Q^{S-1} + ... + \alpha_1 Q + \alpha_0$ ($S \geq 1$ & $\alpha_s > 0$ ($s = 0, ..., S$)). In the Appendix, we also propose a method to derive the equilibrium outcome under the scoring auction without specifying the functional forms of the winning bidders' costs when the sample size is large.

For various types of the cost functions of quality levels, we identify the distribution function of the marginal costs ($F_{\theta_{1:N}}(\cdot)$) and the functional forms of costs for firm $i = 1, ..., K$. Moreover, we can show $F_{\theta_{1:N}}(\cdot) = F_\theta(\cdot)^N$ on the basis of the bidder symmetry, independence of marginal costs (cost parameters) and the characteristic of the order statistics. This enables us to identify $F_\theta(\cdot)$.

5 Estimation Methods

Auction characteristics vary across K auctions. Let x_k, $k = 1, ..., K$, be covariates characterizing the auctioned contracts and N_k ,$k = 1, ..., K$, be the number of bidders in each auction. The covariates x_k are used to control for heterogeneity across auctioned contracts. We estimate the costs of the winning bidders by following the approach of single covariate. This approach is adopted in Elyakime et al. (1994), Li and Perrigne (2003) and Marion (2007). We consider that the cost distribution changes only through the appraisal value because the quality score is correlated with the reserve price as shown in the previous section and the appraisal value is constructed as about 70% of the reserve price.

Thus, we denote the distribution function of the winning bids and the corresponding density function described above as $G_W(\cdot|x_k)$ and $g_W(\cdot|x_k)$. We also denote the distribution function of reserve prices and the corresponding density function as $H(\cdot|x_k)$ and $h(\cdot|x_k)$. Using equation (3), the winning bidders' estimated costs are written as:

$$\hat{c}^k_{1:N} = w_k + E(P_k|x_k) - \frac{(1 - \hat{G}_W(w_k|x_k))(1 - \hat{H}(w_k|x_k))}{\frac{N_k-1}{N_k}\hat{g}_W(w_k|x_k)(1 - \hat{H}(w_k|x_k)) + (1 - \hat{G}_W(w_k|x_k))\hat{h}(w_k|x_k)}$$

where

$$\begin{aligned}
&\hat{E}(P|x) = \hat{\beta}x \\
&\hat{G}_W(w|x) = \frac{\hat{G}(w,x)}{m(x)} = \frac{\frac{1}{Kh_W}\sum_{k=1}^{K} 1\mathbb{I}(W_k \leq w)k(\frac{x-x_k}{h_W})}{\frac{1}{Kh_x}\sum_{k=1}^{K} k(\frac{x-x_k}{h_x})} \\
&\hat{H}(w|x) = \frac{\hat{H}(w,x)}{m(x)} = \frac{\frac{1}{Kh_R}\sum_{k=1}^{K} 1\mathbb{I}(R_k \leq w)k(\frac{x-x_k}{h_R})}{\frac{1}{Kh_x}\sum_{k=1}^{K} k(\frac{x-x_k}{h_x})} \\
&\hat{g}_W(w|x) = \frac{\hat{g}(w,x)}{m(x)} = \frac{\frac{1}{Kh_w{}^2}\sum_{k=1}^{K} k(\frac{w-W_k}{h_w})k(\frac{x-x_k}{h_W})}{\frac{1}{Kh_x}\sum_{k=1}^{K} k(\frac{x-x_t}{h_x})} \\
&\hat{h}(w|x) = \frac{\hat{h}(w,x)}{m(x)} = \frac{\frac{1}{Kh_r{}^2}\sum_{k=1}^{K} k(\frac{w-R_k}{h_r})k(\frac{x-x_k}{h_r})}{\frac{1}{Kh_x}\sum_{t=1}^{K} k(\frac{x-x_k}{h_x})}
\end{aligned}$$

where h_W, h_w, h_R, h_r and h_x are the bandwidths and $k(\cdot)$ is a kernel function.

We discuss the choice of kernel functions and the bandwidths. We use the triweight kernel function that is commonly used in the structural estimations of auctions: $K(u) = \frac{35}{32}(1 - u^2)^3 1\mathbb{I}(|u| \leq 1)$. The triweight kernel function has compact support. Regarding the choice of the bandwidths, we have $h_W = c_W[logK/K]^{1/(2R+3)}$, $h_w = c_w[logK/K]^{1/(2R+4)}$ $h_R = c_R[logK/K]^{1/(2R+3)}$, $h_r = c_r[logK/K]^{1/(2R+4)}$

and $h_x = c_x[logK/K]^{1/(2R+3)}$. The constants c are chosen by the so-called rule of thumb. We set $R = 1$. Thus, we use $h_W = 2.978 \times 1.06 \times \hat{\sigma}_W K^{-0.2}$, $h_R = 2.978 \times 1.06 \times \hat{\sigma}_R K^{-0.2}$, $h_w = 2.978 \times 1.06 \times \hat{\sigma}_W K^{-1/6}$, $h_r = 2.978 \times 1.06 \times \hat{\sigma}_R K^{-1/6}$ and $h_x = 2.978 \times 1.06 \times \hat{\sigma}_x K^{-1/6}$ where σ is the standard deviation of each variable.

To decrease the skewness of bid data, we use a method exploited by Li and Perrigne (2003) and Marion (2007). We transform the data of bids and reserve prices into a logarithmic function. We then have equation (3) written by the transformed winning bids and transformed reserve prices.

$$c_{1:N} = wd + \frac{exp(wd)}{\frac{N-1}{N}\frac{g_{wd}(wd)}{1-G_{wd}(wd)} + \frac{h_{Rd}(wd)}{1-H_{Rd}(wd)}} + E(P)$$

where $wd \equiv \log w$ and $Rd \equiv \log r$. G_{wd} and g_{wd} are the distribution function of $\log w$ and its corresponding density functions. H_{Rd} is the distribution function of $\log r$ and h_{Rd} is the corresponding density. We use (3) written by the logarithmic transformation to estimate the winning bidders' costs.

A problem with kernel estimators has biases near the boundaries of the support. To correct biases, we perform a trimming. We follow a trimming rule proposed by Guerre et el. (2000).

We describe the method of estimating the marginal cost ($\theta_{1:N}$) and the fixed cost (α) in the cost function in each auction. For simplifications of notations, we denote the winning bidder's cost by c and the marginal cost by θ. We need to find K firms which perform two projects under the same cost function to apply the identification method of θ and α proposed in the previous section. However, it is difficult to find the same firms twice in the data set for our analysis because as the summary statistics show, most of the firms win only once in the entire period for our analysis. Hence, we assume two firms which have the closest estimated costs of contracts as one firm. Thus, we choose $\hat{c}^1$ and $\hat{c}^2$ which are the closest winning bidders' estimated costs of contracts. Besides that, we choose $\hat{c}^1$ and $\hat{c}^2$ awarded on the auction dates which differ in six month. We construct L combinations of $\hat{c}^1$ and $\hat{c}^2$, where $2L$ is the number of auctions. The choice rule enables us to obtain $\hat{\theta}$ and $\hat{\alpha}$ by solving the following simultaneous equation:

$$\hat{c}^1 = \hat{\theta}\underline{Q}^1 + \hat{\alpha} \qquad \text{and} \qquad \hat{c}^2 = \hat{\theta}\underline{Q}^2 + \hat{\alpha}$$

where we know $\hat{c}^1$, $\hat{c}^2$, $\underline{Q}^1$, $\underline{Q}^2$ from the estimated values of the winning bidders' costs and the quality scores. We make the combinations of ($\underline{Q}^1$,$\hat{c}^1$) and ($\underline{Q}^2$,$\hat{c}^2$) for each types of the work projects separately. As a result, we have about 350 combinations for bridge work and about 90 combinations for painting work.[19]

[19]Since bridge work consists of four types of construction works (upper structure of steel bridge, prestressed concrete bridge, bridge construction and maintenance in civil engineering work, bridge maintenance and rehabilitation), we choose

Selecting the closest winning bidders' estimated costs of contracts is based on the idea that two firms which receive similar contract sizes tend to have similar cost functions. In the data set for our analysis, we can interpret that firms which have the closest estimated costs of contracts have the same cost function because the small business set-aside program is applied to award about 60% of the total contracts for bridge work. In the market for bridge work, small (large) firms with the small (large) number of engineers employed and small construction revenue tend to participate in auctions in which small (large)-scale contracts are awarded. In the market for painting work, there are no firms which are regarded as major construction companies. Moreover, for both of the work projects, we do not find extremely large firms because for each work project, the top share firm accounts for less than 3% of the total contracts in the entire period for our analysis. Therefore, we consider that two different firms selected based on the choice rule have the same θ and α.

The functional form of $V(Q)$ is necessary to derive the equilibrium quality bid and social welfare under the scoring auction. The functional form of $V(Q)$ is unobservable in the data set, while the secret reserve price (r), which is considered as the government's value of a contract, is observable.[20] In addition, the quality score of work ($\underline{Q}$) is also observable. In this paper, we consider that the government's valuation of a contract is associated with the quality score of work because both of the reserve price and the quality score stem from the specification which is presented by the government in the phase of designing the contract. While the quality score of work is assigned after the completion, it is considered to be the quality level determined by the government at the time of designing the contract because of the review of the quality of work during construction and after the completion. Thus, we assume that $V(Q) = a \log Q$ where a is a parameter and then calculate a in each auction by using $v_B(= r + E(P))$ and $\underline{Q}$.

6 Estimation Results and Counterfactual Experiments

6.1 Estimation Results

Tables 6 reports the estimated marginal costs $\hat{\theta}$ and fixed costs $\hat{\alpha}$ in the cost functions for the two work projects. For bridge work, the average of the marginal costs is 4.95 million and that of the fixed costs is about −279.15 million. The median of the marginal costs is 0.77 million and that of the fixed costs is about 24.04 million. With regard to painting work, the average marginal cost is 0.54 million and

the combination of ($\underline{Q}^1$,$\hat{c}^1$) and ($\underline{Q}^2$,$\hat{c}^2$) for each work project respectively.

[20] In this procurement setting, it is theoretically shown that the secret reserve price is equal to the government's private value of a contract. Li and Perrgne (2003) and Flambard and Perrigne (2006) assume that the reserve price is equal to the government's private value to compute the optimal reserve price.

the average fixed cost is −21.79 million. The median marginal cost is 0.23 million and the median fixed cost 4.30 million. As shown in Figure 2, the variable cost ($\hat{\theta}Q$) accounts for the large proportion of the estimated cost for both work projects.

We observe the differences in the cost functions between bridge work and painting work in terms of the marginal cost per the estimated cost and the fixed cost per the estimated cost. They are represented by $\hat{\theta}/\hat{c}$ and $\hat{\alpha}/\hat{c}$. This normalization allows us to conduct a direct comparison of the marginal cost and the fixed cost across the two work projects which differ in the size of a contract.

Figure 3 shows the cost functions normalized by the estimated costs and the differences of the two work projects graphically. As the figure shows, we observe that the marginal cost is larger for painting work, while the fixed cost is smaller for painting work. Table 7 present the estimated marginal costs and the estimated fixed costs which are normalized by the estimated costs. Table 7 indicates that the average of the marginal costs normalized by the estimated costs ($\hat{\theta}/\hat{c}$) is 0.05 for bridge work and 0.06 for painting work. Hence, on average, the table shows that the marginal cost for bridge work is slightly smaller than that for painting work. On the other hand, the average of the fixed costs is larger for bridge work compared with painting work. With regard to the median, we see the same tendency. These estimation results suggest that the marginal cost of improving the quality of work is lower for bridge work compared to painting work, while the ratio of fixed cost accounting for the total cost is larger for bridge work relative to painting work.

We examine the uncertainty of the marginal cost ($\hat{\theta}/\hat{c}$) from the government's perspective. In particular, we examine which types of the work projects are more attractive to make bidders reveal their private information through scoring auctions. This empirical investigation is important when the government incurs large operational costs to review design proposals in scoring auctions. Table 8 shows the variances of $\hat{\theta}/\hat{c}$ across the quality scores ($\underline{Q}$) for the two work projects. If the variance of $\hat{\theta}/\hat{c}$ is small, it is easy for the government to set the optimal quality level without using scoring auctions because the uncertainty is low. However, if the variance of $\hat{\theta}/\hat{c}$ is large, it should be useful for the government to implement scoring auctions to induce bidders to reveal their information because of the large uncertainty. According to Table 8, on average, the variance of $\hat{\theta}/\hat{c}$ is larger for painting work relative to bridge work, but the average of the variance may be affected by outliers included in the data of painting work. When we observe the variance of $\hat{\theta}/\hat{c}$ across the quality scores ($\underline{Q}$), the variance of $\hat{\theta}/\hat{c}$ for bridge work is basically larger compared with painting work. These estimation results suggest that the government is faced with more technical uncertainty about construction practices for bridge work. Hence, these estimation results imply that it is more useful for the government to implement scoring auctions for bridge work.

6.2 Counterfactual Experiments

In counterfactual experiments, we focus on the analysis of social welfare and the quality of work under the scoring auction introduced by Che (1993). We analyze the equilibrium outcome under the scoring auction with the scoring rule, $s = a \log Q - b$. $Q_O(\hat{\theta})$ is $\frac{a}{\hat{\theta}}$ and social welfare is $a \log \frac{a}{\hat{\theta}} - (a + \hat{\alpha})$.[21]

We analyze which types of the work projects achieve the high quality of work and large social welfare. As the estimation results of the cost functions show, the normalized marginal cost is smaller for bridge work compared with painting work. Given the scoring rule, the optimal quality under the scoring auction suggests that implementing scoring auctions is more effective to increase the quality of work when the marginal cost of improving the quality of work is smaller. Hence, we expect that for bridge work projects, scoring auctions are more effective to improve the quality of work because the normalized marginal cost is smaller for bridge work compared with painting work. However, with regard to social welfare, we need to consider the presence of the fixed costs which vary across contracts because social welfare is affected by the magnitude of fixed cost. Hence, when comparing bridge and painting work with regard to social welfare, we face a trade-off between the small marginal cost and the large fixed cost.

Table 9 shows that the quality of work and social welfare under the scoring auctions are larger relative to those under price-only auctions observed in the data set. Moreover, we find that the impacts of the introduction of the scoring auctions are larger for bridge work compared with painting work. For bridge work, the welfare gain is 5.5% and the quality of work rises by 14%. With regard to painting work, the welfare gain is 3.6% and the quality of work increases by 11%. The net value of the welfare gain is about JPY 2.5 million per contract on average for bridge work and JPY 0.40 million per contract on average for painting work. Hence, we find that when the scoring auctions are implemented, the impacts of the quality of work and the welfare gain are larger for bridge work. The welfare gain is affected by the magnitude of the marginal costs because the normalized marginal cost of the cost function is smaller for bridge work compared with painting work.

7 Conclusion

In this paper, we quantify the benefits of a scoring auction over a price-only auction. We develop a structural model of a price-only auction which enables us to simulate the equilibrium outcome of a scoring auction as a counterfactual scenario. For our empirical analysis, we use a unique data set in

[21] We find that for a number of contracts, the optimal quality levels under the scoring auctions is attained at the boundary solutions ($\underline{Q}$ or $\bar{Q}$ (= 100)).

price-only auctions including information on the quality of work reviewed at the time of completion in addition to the number of bidders and the winning bid. This approach enables us to evaluate the quantitative performance of scoring auctions in comparison with price-only auctions without using scoring auctions' data. In addition, our approach achieves the identification of various types of the cost functions of quality levels and derives the optimal quality levels under scoring auctions without assuming the functional forms of the costs when the sample size is large.

We provide two sources of potential benefits of using scoring auctions and quantify their impacts. The first is the difference in the magnitude of the marginal cost of improving the quality of work. The second is the government's uncertainty of the winning bidders' private information included in the cost functions. We evaluate the quantitative performance of scoring auctions for large-scale and complex projects with small-scale and simple projects, for example, constructing bridges and painting work on the road. The estimation results suggest that the cost structures differ in the marginal cost of improving the quality level and technical uncertainty between both work projects.

The counterfactual simulations show that for painting work, the quality of work improves by about 11 % and the welfare gain is about 3.5 % (JPY 0.39 million) under the scoring auctions and for bridge work, the quality of work rises by about 14 % and the welfare gain is about 5.5 % (JPY 2.5 million) under the scoring auctions. These results suggest that the differences of the performance of scoring auctions between the two work projects are consistent with the implication by Goldberg (1977) and Bajari, McMillan and Tadelis (2009) in that for the procurement of complex projects, scoring auctions, which give incentive for contractors to exploit their expertise, perform better than price-only auctions.

A policy suggestion of our results is that the government should use scoring auctions to award large-scale and complex projects such as bridge work and tunnel work. However, when awarding those work projects under scoring auctions, the government may need to incur large operational costs to review design proposals. We leave the identification and estimation of operational costs through the usage of the data of scoring auctions to future research because in this paper, the data of price-only auctions is used.

8 Appendix

8.1 Covariates Used in Preliminary Analysis

We provide the definitions of the variables of geological conditions around the project sites. The variables of the geological conditions are constructed based on the GIS (Geographic Information System) data produced by Wakabayashi et al. (2005) and publicly available from the MLIT website.[22] The GIS data produced by Wakabayashi et al. (2005) is 1 kilometer mesh data. This data is constructed based on AVS30 that is an index of susceptible surface ground conditions by earthquakes and represents the condition of surface ground at a site.[23] By using the GIS data, we provide four variables of geological factors that affect the execution of works in Japan on the basis of Ikeda (1986): the conditions of surface ground, faults, landslides and liquefaction. The variable of surface ground conditions represents the surface geological and topographical conditions within 1 kilometer radius of the project site. This variable is negatively correlated with the softness of surface ground due to the characteristics of AVS30. This variable takes from 100 (bad surface ground condition) to 740 (good surface ground condition). The variable of the condition of faults measures the condition of faults within 1 kilometer radius of the project site. The range of this variable is from 0 (no risk for faults) to 1 (risk for faults). The variable of the condition of landslides represents whether the area within 1 kilometer radius of the project site is affected by landslides. This variable also takes from 0 (no risk for landslides) to 1 (risk for landslides). The variable of liquefaction provides the condition of liquefaction within 1 kilometer radius of the project site. This value takes from 1 (high risk for the liquefaction) to 4 (low risk for the liquefaction). For projects covering several points, we take the average of the values of geological conditions.

We present how to construct the variables of meteorological conditions around the project sites.[24] In Japan, there are totally about 1000 meteorological observatories. The data of meteorological conditions is publicly available from the Japan Meteorological Agency website. The data is monthly data. We use the data which is the closest observatory to the project site. The variable of the amount of rainfall represents the average amount of rainfall at the project site in each year. The variable of temperature conditions is the minimum temperature at the project site in each year. For projects covering several points, we use the average values of meteorological conditions at the project points.

We describe the variables of business environments around the project sites: the construction

[22] The data of landslides and faults is available from http://nrb-www.mlit.go.jp/kokjo/inspect/landclassification/download/.
[23] The Cabinet office uses this data to make a map to measure earthquakes.
[24] See http://www.data.jma.go.jp/obd/stats/etrn/.

materials prices, the oil price and the income level.[25] The variable of the construction materials prices consists of ten kinds of representative construction materials prices used to perform public-works projects. It includes the prices of steel, the secondary product of concrete, fresh concrete, cement, aggregate, asphalt mix, bituminous material, special steel and temporary material. This variable is calculated monthly by Paasche index of these prices and constructed at each regional bureau level. We exploit the material price recorded at the month of completion of work for our analysis. The oil price is monthly data and available from foreign trade statistics. The variable of the business environment measures the average annual income per taxpayer at about 1800 cities in Japan. In order to construct this variable, we use the data of the city that is the nearest to the project site in each year. When projects are performed at several locations, we take the average of the values of economic environments.

8.2 Nonparametric Identification of Cost Functions of the Quality Levels

We present an approach to simulate the equilibrium outcome of the scoring auction introduced by Che (1993) without assuming the functional form of the cost. The cost function is assumed to be $C_Q(Q,\theta) > 0$ and $C_\theta(Q,\theta) > 0$ over $[\underline{Q}, \bar{Q}]$. In this environment, the optimal quality is set as $\underline{Q}$ as shown in the previous section. Moreover, we obtain $c_{1:N} = C(\underline{Q}, \theta_{1:N})$ and the quality score of work $\underline{Q}$ from the equilibrium relation and the data set. We rewrite the cost function as $C(Q, \theta_{1:N}) = \tilde{C}(Q, \tilde{\theta})$ where $\tilde{\theta} \sim U[0,1]$. We denote $\tilde{C}(Q, \tilde{\theta})$ as $\tilde{C}(Q)$.

The idea of identification is similar to the method provided in the previous section. We identify $\tilde{C}(\cdot)$ nonparametrically when we assume that the number of observations is large and large number of projects are performed under the same cost function (the KN observations in our data set consist of N firms which receive K contracts located at different project sites.). We then have K observations $(\underline{Q}^1, {c_i}^1), ..., (\underline{Q}^K, {c_i}^K)$, where ${c_i}^j = \tilde{C}_i(\underline{Q}^j, \tilde{\theta}_i) = \tilde{C}_i(\underline{Q}^j)$ for contract $j = 1, ..., K$ and firm $i = 1, ..., N$. In the same way as the previous section, the functional form of the winning bidder's cost (i.e. $\tilde{C}_i(\cdot)$ and $\tilde{\theta}_i$) is unchanged, while ${c_i}^j$ vary with $\underline{Q}^j$ which exogenously changes across contracts. In this environment, we obtain $\tilde{C}_i(\cdot)$ nonparametrically in the same method as Lu and Perringe (2008). Let c_i^j follows $F_{c_i}(\cdot)$ and $\underline{Q}^j$ follows $G_{\underline{Q}}(\cdot)$. Let $c_i(\alpha)$ and $\underline{Q}(\alpha)$ be the α-quantiles of the distribution functions $F_{c_i}(\cdot)$ and $G_{\underline{Q}}(\cdot)$ with $\alpha \in [0,1]$. Hence, $c_i(\alpha) = F_{c_i}^{-1}(\alpha)$ and $\underline{Q}(\alpha) = G_{\underline{Q}}^{-1}(\alpha)$. Utilizing the FOC, we obtain $F_{c_i}^{-1}(\alpha) = \tilde{C}_i(G_{\underline{Q}}^{-1}(\alpha))$. This allows us to identify $\tilde{C}_i(\cdot) = \tilde{C}(\cdot, \tilde{\theta}_i)$ $(i = 1, ..., N)$ nonparametrically because we know N, $F_{c_i}(\cdot)$ and $G_{\underline{Q}}(\cdot)$ from the equilibrium relation and the data set.

[25]For the construction materials prices, we use the data constructed by Economic Research Association. The data of the income level is obtained from the data of population and households provided by Statistical Bureau.

Specifying a scoring rule, we can compute $Q(\tilde{\theta})$ and $V(Q(\tilde{\theta})) - \tilde{C}(Q(\tilde{\theta}), \tilde{\theta})$ under the scoring auction. This approach allows us to obtain the optimal quality levels, social welfare and the equilibrium prices under the scoring auctions without specifying the functional forms of the costs.

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Table 1: Small-business Set Aside

		Open Auctions		Invited Auctions	
Size of a contract	Rank of a responsible bidder	Number of potential participants	Number of contracts	Number of invited bidders	Number of contracts
A	A	440 (89 %)	66 (94 %)	-	-
	B	22	2	-	-
	C	30	3	-	-
	sum	492	71	-	-
B	A	0	0	9	3
	B	0	0	466 (92 %)	52 (87 %)
	C	0	0	32	5
	D	-	-	0	0
	sum	0	0	507	60
C	A	-	-	36	2
	B	-	-	409	48
	C	-	-	27163 (98 %)	2585 (98 %)
	D	-	-	41	4
	sum	-	-	27649	2639
D	A	-	-	0	0
	B	-	-	0	0
	C	-	-	280	28
	D	-	-	4669 (94 %)	481 (94 %)
	sum	-	-	4949	509

Note: For this information, see http://www.mlit.go.jp/page/kanbo01_hy_003695.html.

Table 2: Summary Statistics for Bridge Work and Painting Work

Bridge Work		Painting Work	
Variable	Mean (Standard deviation)	Variable	Mean (Standard deviation)
Reserve price	1.22E+08	Reserve price	2.77E+07
	(1.44E+08)		(2.25E+07)
Appraisal value	9.42E+07	Appraisal value	1.98E+07
	(1.16E+08)		(1.65E+07)
Relative winning bid	0.91	Relative winning bid	0.85
	(0.09)		(0.14)
Quality score of work	73.63	Quality score of work	72.10
	(4.65)		(3.58)
Contractual length	217.70	Contractual length	150.93
	(96.20)		(65.00)
Number of actual bidders	8.07	Number of actual bidders	10.66
	(3.42)		(3.66)
Number of potential bidders	9.11	Number of potential bidders	11.19
	(3.28)		(3.85)
Income	3074358	Income	3112648
	(546271.3)		(560159.7)
Precipitation	1493.15	Precipitation	1426.75
	(483.35)		(469.28)
Minimum temperature	2.95	Minimum temperature	3.07
	(2.79)		(2.78)
Material price	103.90	Oil price	44119.35
	(5.77)		(2917.67)
Surface ground	402.96		
	(183.85)		
Fault	0.05		
	(0.14)		
Landslide	0.10		
	(0.26)		
Liquefaction	3.19		
Sample size	776	Sample size	280

Note: Standard deviations are in parentheses.

Table 3: Regression Results on Winning Bids and Relative Winning bids for Bridge Work

Dependent variable	Log of winning bid	Dependent variable	Log of winning bid
Estimator	OLS	Estimator	OLS
Number of potential bidders	-0.003**	Log of number of potential bidders	-0.022***
	(0.0015)		(0.008)
Sample size	776	Sample size	776
R-squared	0.98	R-squared	0.98

Dependent variable	Relative winning bid	Dependent variable	Relative winning bid
Estimator	OLS	Estimator	OLS
Number of potential bidders	-0.003***	Log of number of potential bidders	-0.025***
	(0.001)		(0.007)
Sample size	776	Sample size	776
R-squared	0.07	R-squared	0.07

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are in parentheses. All regressions include a constant term, auction-level characteristics, the variables of geological conditions, the variables of meteorological conditions, the variable of economic environment and 11 monthly dummy variables.

Table 4: Estimation Results on Winning Bids and Relative Winning Bids for Painting Work

Dependent variable	Log of winning bid	Dependent variable	Log of winning bid
Estimator	OLS	Estimator	OLS
Number of potential bidders	-0.007**	Log of number of potential bidders	-0.067**
	(0.003)		(0.032)
Sample size	280	Sample size	280
R-squared	0.94	R-squared	0.94

Dependent variable	Relative winning bid	Dependent variable	Relative winning bid
Estimator	OLS	Estimator	OLS
Number of potential bidders	-0.007***	Log of number of potential bidders	-0.071***
	(0.002)		(0.025)
Sample size	280	Sample size	280
R-squared	0.300	R-squared	0.290

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are in parentheses. All estimation models include a constant term, auction-level characteristics, the variables of geological conditions, the variables of meteorological conditions, the variable of economic environment and 11 monthly dummy variables.

Table 5: Estimation Results on the Quality Score of Work for Bridge Work and Painting Work

Dependent variable	Quality score of work	Dependent variable	Quality score of work
Estimator	OLS	Estimator	OLS
Log of reserve price	0.812***	Log of reserve price	0.710**
	(0.234)		(0.343)
Income	8.56E-08	Income	-6.46E-07
	(3.82E-07)		(4.29E-07)
Material price	0.073**	Oil price	2.51E-05
	(0.037)		(7.44E-05)
Precipitation	0.001*	Precipitation	-0.001*
	(0.00038)		(0.0005)
Minimum temperature	-0.097	Minimum temperature	0.217**
	(0.069)		(0.105)
Surface ground	0.001		
	(0.002)		
Fault	-0.888		
	(1.209)		
Landslide	0.018		
	(0.749)		
Liquefaction	-0.075		
	(0.366)		
Sample size	776	Sample size	280
R-squared	0.06	R-squared	0.09

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are parentheses. All estimation models include a constant term, auction-level characteristics, the variables of geological conditions, the variables of meteorological conditions, the variable of economic environment and 11 monthly dummy variables.

Table 6: Estimation Results on the Cost Functions

	Sample size	$\hat{c}$ (ave) (mils)	$\hat{\theta}$ (ave) (mils)	$\hat{\alpha}$ (ave) (mils)	$\hat{\theta}$ (med) (mils)	$\hat{\alpha}$ (med) (mils)
Bridge work	696	94.63	4.95	-279.15	0.77	24.04
Painting work	189	17.97	0.54	-21.79	0.23	4.30

Table 7: Estimation Results on the Normalized Cost Functions

	Sample size	$\hat{\theta}/\hat{c}$ (ave)	$\hat{\alpha}/\hat{c}$ (ave)	$\hat{\theta}/\hat{c}$ (med)	$\hat{\alpha}/\hat{c}$ (med)
Bridge work	696	0.05	-2.94	0.008	0.394
Painting work	189	0.06	-3.47	0.011	0.244

Table 8: The Standard Deviations of $\hat{\theta}/\hat{c}$ for Bridge Work and Painting Work

Painting		Bridge	
Quality score	$\hat{\theta}/\hat{c}$ (std dev)	Quality score	$\hat{\theta}/\hat{c}$ (std dev)
70	1.13	70	0.01
71	0.04	71	0.18
72	0.10	72	0.08
73	0.05	73	0.19
74	0.06	74	0.14
75	0.06	75	0.24
76	0.07	76	0.18
77	0.12	77	0.11
78	0.14	78	0.09
79	0.02	79	0.08
80	Non	80	0.06
Average for full sample	0.28	Average for full sample	0.15

Table 9: Results of Counterfactual Simulations

Bridge work:	Price-only auction	Scoring auction	Difference	Difference/Price-only
Quality	73.84	83.83	9.99	0.14
Social welfare (JPY; mils)	45.08	47.56	2.48	0.05

Painting:	Price-only auction	Scoring auction	Difference	Difference/Price-only
Quality	72.43	80.49	8.06	0.11
Social welfare (JPY; mils)	10.89	11.28	0.39	0.04

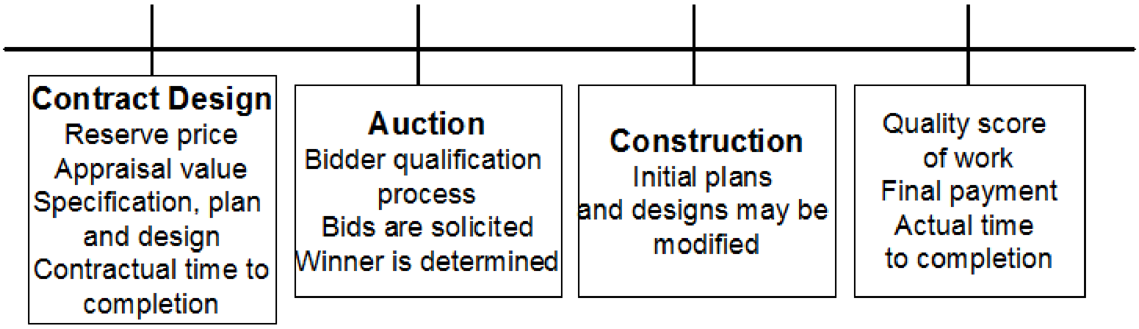

Figure 1: Public-works Procurement

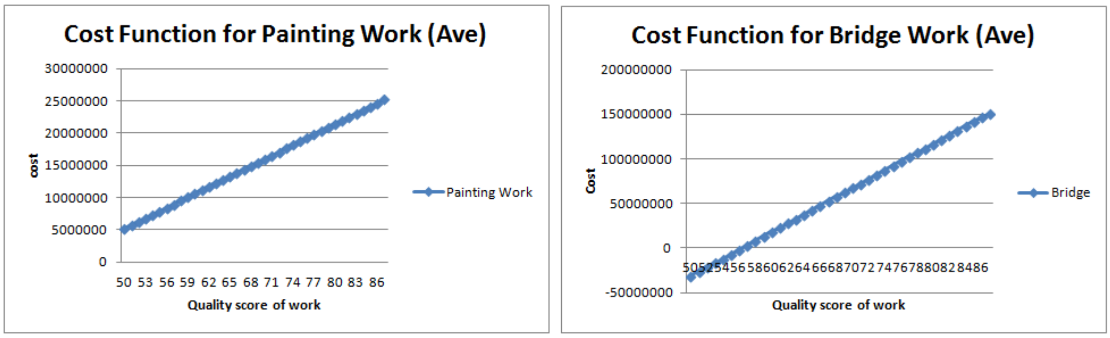

Figure 2: The Cost Functions: Bridge Work and Painting Work

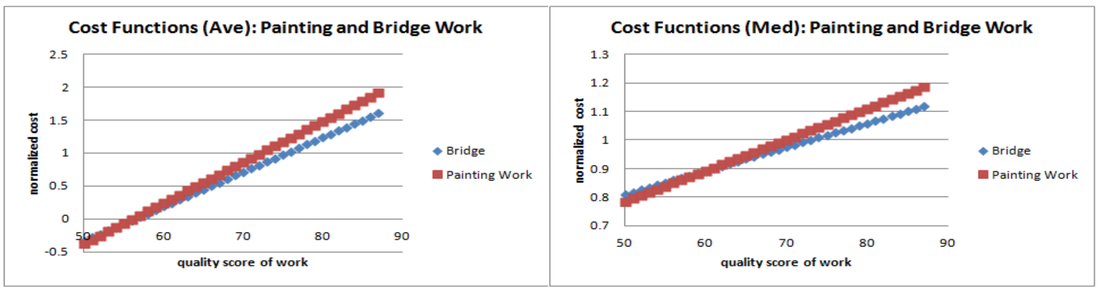

Figure 3: Comparison between Bridge Work and Painting Work

Chapter 3. The Effects of Relaxing Entry Regulations on Price and Quality: Evidence from Public Procurement Auctions

1 Introduction

Entry regulations are common in many markets. The presence of medical licenses, qualifications for becoming a lawyer and import restrictions can be suggested as the examples. When the government relaxes entry regulations, many new firms enter a market. Large participation in the market can intensify competition and reduce prices. However, the new firms possibly supply poor-quality products due to the lack of their experiences. The government is concerned not only with the prices but also with the quality levels because the prevalence of medical malpractice, fraud schemes and imported poisoned foods leads to dismal outcomes. Therefore, it is important to quantify the impacts of relaxing entry regulations in terms of both price and quality.

Entry regulations are implemented in public procurement which holds $13-20\%$ of GDP on average worldwide.[1] In Japan, some European countries and developing countries, the governments implement invited (restricted) auctions to award contracts.[2] In an invited auction, only particular firms selected by the government are allowed to bid. Hence, the auction possibly leads to repeated participation of particular firms and reduces competition. In this situation, it is also possible that only inefficient firms are selected due to the asymmetric information between the government and firms. However, the governments consider that invited auctions are effective to ensure ex post performance including the quality of work which may be worsened by not only the uncertainty at the time of bidding (the adverse selection problem) but also the moral hazard problem during construction or production process.[3] In contrast to the invited auction, in an open auction, any prospective firms can voluntarily submit bids if they satisfy some minimum requirements including financial conditions.

[1] See http://www.oecd.org/gov/ethics/oecdjointlearningstudies.htm

[2] Countries in EU are allowed to use invited (restricted) auctions in public procurement. The selection rules of bidders used in some countries are close to the rules used in Japan. For this information, see OECD (2010). In public procurement in many developing countries, open auctions are not required when the value of a contract is less than a certain threshold. See http://www.oecd.org/site/adboecdanti-corruptioninitiative/37575976.pdf.

[3] It is theoretically shown that government entry regulations increase quality and welfare when the informational asymmetry between the government and contractors arises (Leland (1979) and Shapiro (1986)). Ye (2007) examines the effects of an indicative bidding which is a kind of entry regulations. Calzolari and Spagnolo (2009) show that in procurement auctions, an entry regulation through relational contracting is beneficial for the government because it gives rent to contractors to improve quality levels. In real-world public-works procurement, the moral hazard problem arises due to unanticipated productivity shocks during project construction (Lewis and Bajari (2014)). During project construction, a contractor has an incentive to reduce her efforts to cut the cost of a project because of the moral hazard problem (McAfee and McMillan (1986)). Bajari, Houghton and Tadelis (2014) structurally estimate adaptations costs incurred by contractors due to contractual incompleteness.

Although the introduction of open auctions can intensify competition, relaxing the regulation of entry possibly worsens ex post performance because inexperienced new firms, which fail to estimate the costs of projects appropriately, may win auctions. Despite the prevalence of entry regulations in public procurement, there is still a scarcity of empirical research that uses information on ex post performance to quantify the impacts of relaxing entry regulations.

In this paper, we provide the causal effects of introducing open auctions in terms of procurement costs and the quality of construction works by exploiting a nationwide policy change in public-works procurement in Japan. Each local agency under the Ministry of Land, Transportation and Infrastructure (MLIT) used invited auctions to award contracts with a reserve price below JPY 720 million (approximately USD 7.2 million) with some exceptions.[4] However, large-scale collusion was exposed in the procurement auctions under the MLIT in May 2005. Hence, from October 2005, the local agencies had to implement open auctions to award contracts with a certain range of the size of a contract and increase the range year after year. We implement the IV method to compare the outcomes of procurement under invited auctions with those of procurement under open auctions based on the policy change of auctions because contracts which are awarded through open auctions are in many ways different from contracts which are awarded through open auctions and the unobserved heterogeneity possibly introduces biases in OLS estimates of the effects of introducing open auctions. We perform before and after comparisons by classifying the sample for our analysis into two distinct time periods because during one period, both open and invited auctions were used within certain range of the size of a contract, while during another period, only open auctions were mandatorily implemented within the range. For our empirical analysis, we consider a (dummy) variable representing two distinct time periods as the instrumental variable because the regional bureaus had to expand the scope of open auctions year after year due to the policy change. We exploit the (dummy) variable as an exogenous change in the choice of auction methods. This empirical analysis gives us the effect of introducing open auctions on contracts which were awarded through invited auctions.

Our unique and rich data set includes information on the final payment and the quality score of work reviewed at the time of completion in addition to the winning bid and the completion time in each contract. In public-works procurement, the final payments determined at the time of completion are frequently higher than the winning bids because the initial designs and specifications tend to be amended due to unanticipated shocks during construction. The quality score comprehensively measures the quality of work. It contains information on the performance of the work such as verticality and horizontality in foundation construction besides information on the completion time. Hence, in

[4] The MLIT has nine local agencies throughout Japan. The local agencies are called regional bureaus and are in charge of public-works procurement in their territory.

this paper, we use two measures of the quality of work (the completion time and the quality score of work) in addition to two measures of procurement costs (the winning bid and the final payment).

An auction mechanism we examine is a scoring auction. Scoring auctions have started to become common worldwide (Asker and Cantillon (2008)). In a scoring auction, the winner is the bidder with the best combination of the price and the evaluation score of the design proposal according to a pre-specified scoring rule. In the auction, bidders submit design proposals besides prices and the government assigns the evaluation scores based on the evaluations of design proposals to every bidder. Che (1993) and Asker and Cantillon (2008) show that a scoring auction gives an incentive for the contractor to exploit her expertise about construction practices, and hence improves social welfare and the government surplus in comparison with price-only auctions. On the basis of the theory, we expect that scoring auctions with open bidding can reduce procurement costs through the decline in the completion time and improve the quality levels due to competitive pressures for design proposals. However, scoring auctions possibly lead to inefficiency and reduce competition when the government manipulates the evaluations of design proposals to make a particular bidder the winner. In this case, consequently, the government favors particular firms and open auctions under scoring designs end up as de facto invited auctions.[5] Since there is little empirical evidence of scoring auctions, we do not know which effects arise in real-world procurement. Therefore, we use the data of scoring auctions to quantify the impacts of open auctions over invited auctions.

The estimation results show that the introduction of open auctions under a scoring design reduces the procurement costs and the completion time, but it does not worsen the quality score of work. The samples of three regional bureaus (Kanto, Shikoku and Kyushu) are separately used to compare open and invited auctions under a scoring design because the timing of the policy change is different between the regional bureaus. For Kanto, the introduction of open auctions leads to the decline in the cost overrun by 12% and the reduction in the delay in completion by 68% despite that quality deterioration does not occur. We find that for Shikoku, the switch to open auctions reduces the final payments by 28% and the delay in completion by 70%, while the policy change does not affect the quality score of work. With regard to Kyushu, the open auction dramatically decreases the cost overrun and the delay in completion, but the quality score of work is not decreased. Therefore, we find that under scoring auctions, the introduction of open auctions lowers the procurement costs and the completion time despite that it does not worsen the quality score of work.

[5]Burguet and Che (2004) show that the outcomes of scoring auctions are inefficient when the government receives bribes and manipulates the evaluations of quality bids. Rezende (2009) shows the opposite theoretical result: under scoring auctions, manipulations in the evaluations of design proposals promote competition by increasing the competitiveness of weaker bidders and leading stronger bidders to submit attractive bids. Milgrom (2004) also argue that by evaluating various attributes of bidders, scoring auctions induce large participation of several types of bidders. These theoretical results suggest a similar result for the effects of bid preferences in asymmetric auctions (Maskin and Riley (2000)).

For robustness checks, we shorten the periods for estimations to cope with unobserved macroeconomic shocks. We confirm that open auctions reduce both the cost overrun and the delay in completion and the estimation results are robust. Moreover, with regard to Kyushu, we perform the difference-in-differences analysis. The estimation results also show that the introduction of open auctions decreases the cost overrun and the delay in completion without worsening the quality score of work.

We provide suggestive evidence on the impacts of new participants. We examine whether the presence of new participants in open auctions intensifies competition. To quantify the impacts of new participants, we treat firms which submit their initial bids in open auctions in the entire period for our analysis as new participants. The impacts of new participants are investigated by using the samples of the three regional bureaus. For Shikoku and Kyushu, the summary statistics show that the presence of new participants in open auctions reduces procurement costs by up to 17%, while it does not worsen the quality score of work. The estimation results for OLS show that for Kyushu, when new participants submit bids in open auctions, the final payments are decreased by up to 7.6%. However, we do not find evidence that the presence of new participants worsen the quality score of work.

In this paper, we highlight ex post performance including the final payments and the quality of work to examine the effects of relaxing entry regulations in public procurement. In particular, this is the first paper that introduces a quality measure which includes qualitative and comprehensive information on the quality of work reviewed after the completion. The usage of the quality score of work is important because the government may be faced with the worsening of the performance of the work because of accelerated completion. The empirical auction literature investigates the effects of promotion on competition in public procurement (see, e.g., De Silva, Dunne and Kosmopoulou (2003), De Silva, Kosmopoulou and Lamarche (2009), Ohashi (2009), Coviello and Mariniello (2014), Coviello, Guglielmo and Spagnolo (2014) and Decarolis (2014)).[6] However, there is still a scarcity of the empirical literature that brings ex post performance such as the quality of work at the time of completion and the final payments in spite of the presence of the moral hazard problem during construction. Therefore, this paper contributes to the literature because our main finding is that the introduction of open auctions reduces the cost overrun and the delay in completion despite that it does not worsen the quality of work which is comprehensively evaluated.

This is the first paper that focuses on scoring auctions to quantify the impacts of open auctions over invited auctions. Several papers (e.g., Che (1993) and Asker and Cantillon (2008)) theoretically

[6]There have been a number of empirical papers which quantify the impacts of promotion on competition in government contracts including power purchase contracts, railway services, social housing and timer sales (see, e.g., Cameron (2000), Chever, Saussier and Yvrande-Billon (2011) and Lalive and Schmutzler (2011)).

analyze scoring auctions, but it is uncertain whether open auctions under scoring designs promote competition due to the presence of the counteracting effects. Coviello, et al. (2014) use the data of average bid designs which are similar to beauty contests, while they evaluate the quantitative performance of open auctions in comparison with invited (restricted) auctions and use information on ex post performance including cost overruns. There is little evidence of scoring auctions with the notable exception of Lewis and Bajari (2011) despite that scoring auctions have started to be prevalent worldwide.[7] Therefore, this paper also contributes to the empirical literature on scoring auctions because our nontrivial results show that open auctions under a scoring design are effective.

The paper is organized as follows. Section 2 presents related literature. Section 3 describes the procurement system, the policy changes and the choice of samples. Section 4 is devoted to show our empirical model, the main estimation results, robustness checks and the effects of new participants. Section 5 offers a conclusion.

2 Procurement System

In this section, we provide the overview of public-works procurement under the Ministry of Land Infrastructure and Transportation (the MLIT) in Japan. The MLIT is responsible for nationwide public-works procurement. In the MLIT, there are eight regional bureaus (Tohoku, Hokuriku, Kanto, Chubu, Kinki, Chugoku, Shikoku and Kyushu) and Hokkaido regional development bureau. These regional bureaus are the local agencies of the MLIT and are in charge of operating the procurement in their territories.

The flow of the procurement is shown in Figure 1. In the phase of designing a project, engineers in a regional bureau present the specification, the plan, the reserve price and the contractual length of the project. The reserve price is constructed on the basis on the initial specification and plan. The reserve price is kept secret at the time of bidding, while it is publicly announced after bids are opened. The appraisal value is set as a minimum price to prevent quality deterioration due to excessive competition. If the lowest bid is lower than the appraisal value, officials in the regional bureau sometimes reject the bid. The appraisal value is also kept secret at the time of bidding, while it is publicly announced after bids are opened.

Any firms which wish to participate in the procurement auctions held by the regional bureaus need to be certified as responsible bidders through a rating system. The rating system evaluates

[7] According to Asker and Cantillon (2008), in the data of scoring auctions, it is difficult to obtain separate information on price and quality due to the problem of binding scores. However, when we perform empirical analysis, we need to have this information to interpret the estimation results.

a firm's financial condition, past history of projects completed, the number of engineers employed and a firm's construction revenue. Every regional bureau constructs the list of responsible bidders based on information of the rating system. They announce the number of responsible bidders in their territory and update the list every one or two years.

In the phase of bidding, the regional bureaus award contracts under auctions. When they put a contract to tender, a bidder qualification process and an auction mechanism were combined. There were four auction methods in the market for our analysis: a scoring auction with open bidding, a scoring auction with invited bidders, a price-only auction with open bidding and a price-only auction with invited bidders.

There are two bidder qualification processes. In an invited auction, only firms selected by officials in a regional bureau are given contract information and are allowed to submit bids. In the auction, the officials select about 10 firms on the basis of information including past history for the performance of similar projects completed, information on the ability of engineers employed, geological conditions around the project site, the distance between a bidder's branch office and the project site, free capacity utilization in addition to the information of the rating system prior to auction. In contrast to the invited auction, in an open auction, any firms can voluntarily submit bids if they satisfy the minimum requirements which include past history of similar projects completed, the distance between a bidder's branch office and the project site and information on engineers employed in addition to the information of the rating system.[8] In this auction, the regional bureaus broadly and publicly advertise a contract about a month prior to auction. The advertisement includes the contract location, the length of the contract in days and a description of the task.

Scoring auctions are used in addition to price-only auctions (first price sealed bid auctions). In a scoring auction, the winning bidder is the bidder with the best combination of the evaluation score of the document related to the quality of work and the price according to a pre-specified scoring rule. In this auction, bidders submit prices and documents related to the quality of work including design proposals. Engineers in the regional bureau evaluate the documents and assign the evaluation scores of the documents to every bidder. They have $10 - 20$ days to evaluate the design proposals. In the market for our analysis, the regional bureaus implement a scoring auction with A/B scoring rule (price over quality ratio scoring rule) where "A" part is the evaluation score of the document and "B" part is the price. The bidder with the largest score receives a contract in the auction if the winner's price is lower than the reserve price.

[8]The differences of the requirements between open and invited auctions seem to be ambiguous. According to people in the construction industry, the minimum requirements in the open auction are less stringent than the requirements in the invited auction. However, we cannot observe the detailed requirements for each contract and the number of firms which satisfy the requirements in each auction due to the restriction of data.

During project construction, the contractor is faced with a lot of problems from geological and meteorological conditions at the project site. In public-works procurement, initial specifications tend to be inadequate and contracts are likely to be incomplete due to unanticipated shocks during project construction. Consequently, initial specifications and plans are often amended during project construction and the final payments are frequently higher than the winning bids. The final payment and actual time to complete a project are determined by negotiations between the contractor and officials in the regional bureau.

Engineers in the regional bureau review the quality of work during construction and at the time of completion, and give the quality score of work based on the evaluation of the quality of work. For contracts with a value of JPY 100 million (approximately USD 1 million) or more, the engineers review the quality of work twice during construction in each contract, while for simple projects, they do not review the quality of work during construction.[9] In the regional bureaus, there are a sufficient number of engineers who have skill at reviewing the quality of work. The quality score of work is constructed based on qualitative attributes. The quality score is composed of the performance of work, the quality of work, the level of completed work, the level of execution management, the system of the execution of work, the safety management, the schedule control (up to these factors, more than 70 % of the score is constituted), the consideration to the environment around the project site, the ingenuity for the execution of work, the ability of engineers, the technology level used to perform work and the legal compliance.[10] The engineers rate the quality score on a scale of 0 to 100 points. The criteria of evaluating the quality score is the same across all types of work projects.

2.1 Policy Changes

In October 2005, open auctions were introduced on a massive scale for contracts with a reserve price that is less than JPY 720 million. Before October 2005, each regional bureau mainly used invited

[9]Before April 2006, for contracts with a value between JPY 100 and 200 million, they review the quality of work once during construction and for contracts with a value of JPY 200 million or more, they review it once or twice during construction.

[10]We are concerned that the quality score used for our analysis is possibly affected by discretion exercised by officials in the government for their private gain including corruption. However, the quality score is reliable because the ranking of Japan is 21th and that of the United States is 17th in the rating of corruption perceptions index (CPI) reported by Transparency International in 2005. The CPI score was 7.3 for Japan and 7.6 for the United States. Corruption levels in the public sector measured by Kaufmann, Kraay and Mastruzzi (2005), which are used in Fisman and Miguel (2007), also show the same tendency as the CPI score. Moreover, we compare 2007 with 2013 for the number of contracts for maintenance and rehabilitation work because we are concerned that officials in the government may manipulate the evaluations of the quality scores to justify the expansion of open auctions in spite of low quality performance. In this case, it increases the number of contracts for maintenance and rehabilitation work 5 or 10 years after the massive introduction of open auctions. However, we confirm that the number of contracts is decreased by 160 and the proportion of maintenance and rehabilitation work to the total contracts remains unchanged. These measures allow us to consider the quality score as reliable.

auctions to award contracts with a reserve price below JPY 720 million.[11] However, in May 2005, large-scale collusive activities were detected in procurement auctions for upper part of steel bridge under the MLIT so that executives in the construction industry and a number of senior officials in the government were arrested. As a result, the switch from invited auctions to open auctions was officially announced, and hence the regional bureaus had to expand the scope of open auctions on a massive scale.

Invited auctions were basically replaced by open auctions in descending order of the size of a contract year after year because officials in the regional bureaus had to implement open auctions for contracts with a reserve price below JPY 720 million. In particular, from October 2005 to March 2006, the implementation of open auctions was mandatory to award contracts with a reserve price of JPY 300 million or more, from April 2006 to March 2007, contracts with a reserve price of JPY 200 million or more had to be awarded through open auctions and from April 2007 to March 2008, contracts with a reserve price of JPY 100 million or more had to be procured through open auctions.

In the same period as the introduction of open auctions, scoring auctions were also extensively introduced to award contracts. In 2005, *bill for ensuring the quality of public works* was established. As a result, scoring auctions have been widely implemented to award not only large-scale and complex projects but also small-scale and simple projects. Hence, the use of scoring auctions has started to become common since November 2005. Price-only auctions were replaced by scoring auctions in descending order of the size of a contract year after year.

2.2 The Choice of Samples

We have the data of public-works procurement operated by the eight regional bureaus from April 2005 to March 2008. We obtain the data from the record of the MLIT. In the period for our analysis, the eight regional bureaus in the MLIT procured 34639 contracts in total. The 34639 contracts consist of 21 types of work projects including electric insulation work, machinery equipment, upper structure of bridge and road painting in addition to the construction of roads. Scoring auctions with open bidding account for 56% of total contracts procured by all the regional bureaus and price-only auctions with invited bidders constitute 37% of them. However, merely 6% of the total contracts were awarded through scoring auctions with invited bidders and merely 1% of them were procured through price-only auctions with open bidding.

We restrict our analysis to general civil engineering work (referred in Japanese as *ippan doboku*),

[11] Before October 2005, open auctions were used to award all the contracts with a reserve price exceeding JPY 720 million and about 10 % of the contracts with a reserve price between JPY 200 and 720 million.

maintenance and rehabilitation work (referred in Japanese as *iji shuzen*) and asphalt paving work (referred in Japanese as *asphalt hosou*) which can be affected by the moral hazard problem through geological and meteorological conditions at the project sites. General civil engineering work and maintenance and rehabilitation work consist of public works associated with road, river and bridge works. General civil engineering work includes large-scale and complex projects, while maintenance and rehabilitation work mainly consists of small-scale and simple projects. These three work projects account for about 70 % of all the public-work contracts procured by the MLIT.[12] Hence, we focus on these three representative public-work contracts.

We choose regional bureaus and the size of a contract that enable us to compare open auctions with invited auctions under the scoring design because scoring auctions with invited bidders are not commonly used.[13] Contracts with a reserve price below JPY 200 million account for about 85% of all the contracts procured by the eight regional bureaus. About 45% of scoring auctions with invited bidders were used to award contracts with a reserve price from JPY 100 to 200 million. About 50% of invited auctions under the scoring design were used in Kanto. Tohoku, Chugoku and Hokuriku used scoring auctions with invited bidders, but three or four auction methods are mixed within a short period of time. In Kinki and Chubu, less than 1% of contracts were awarded through scoring auctions with invited bidders. Hence, we choose the samples of Kanto, Shikoku and Kyushu for contracts with a reserve price from JPY 100 to 200 million.

Figure 2 shows the changes of auction methods for individual regional bureaus in the samples used for our analysis. For contracts with a reserve price from JPY 100 to 300 million, Shikoku used scoring auctions with open bidding exclusively from April 2006, while it implemented scoring auctions with invited bidders and scoring auctions with open bidding between November 2005 and March 2006. The sample mainly consists of contracts with a reserve price from JPY 100 to 200 million. With regard to contracts with a reserve price from JPY 100 to 200 million, Kanto used scoring auctions with invited bidders and scoring auctions with open bidding between August 2006 and March 2007, while it held scoring auctions with open bidding exclusively from April 2007. For contracts with a reserve price from JPY 100 to 200 million, Kyushu implemented scoring auctions with invited bidders and scoring auctions with open bidding between April 2006 and August 2006, while it held scoring auctions with open bidding exclusively from September 2006. Before April 2006, for Shikoku, invited auctions were mainly used for contracts with a reserve price below JPY 100 million. For Kanto and Kyushu, we confirm the same tendency as Shikoku before the complete shift to open auctions. We

[12]According to our data, some of work projects included in 21 types of work projects are procured in only particular regional bureaus. However, these three work projects are procured in the eight regional bureaus.

[13]We basically omit “regional bureau” from the names of regional bureaus later when we describe regional bureaus (e.g. Kanto regional bureau is denoted as Kanto).

exploit the samples of these three regional bureaus separately because of the differences in the timing of the changes of the auction methods.

Table 1 presents the relation between the pace of introducing scoring auctions with open bidding and operational costs for procurement incurred by regional bureaus. For Shikoku, the number of contracts per engineer is less than 1, the budget size per government official is small, and hence 99% of contracts are awarded through scoring auctions with open bidding in 2006. With regard to Kanto and Kyushu, the number of contracts per engineer is more than 1 and the expansion of scoring auctions with open bidding is slower compared with Shikoku. In particular, Kanto shows that the budget size per government official is the largest between the eight regional bureaus, and hence in 2007, 20 % of auctions were invited auctions despite that the other regional bureaus scarcely used invited auctions. Hence, Table 1 suggests that low operational costs and work volume enable Shikoku to expand open auctions earlier compared with Kanto and Kyushu.[14] Based on the evidence, we consider that the early introduction of open auctions in Shikoku in 2006 was due to causes unrelated to the effects of scoring auctions with open bidding.

2.3 Data and Measurement Issues

In the data set used for our analysis, for each contract, we observe information on the reserve price, the project site, the contractual time to complete the work, the actual time to complete the work, individual bids and their identity, the identity of firms invited by the government in an invited auction, the identity of firms which show their interests for a project in an open auction, the winning bid, the final payment and the quality score of work.[15]

There are three measures of procurement costs: the relative winning bid, the relative final payment and the cost overrun. The relative winning bid (final payment) is defined as the winning bid (final payment) represented as a ratio of the reserve price. The cost overrun is constructed by the difference between the final payment and the winning bid divided by the winning bid. The relative winning bid measures how the introduction of open auctions influences the bidding behavior. The final payment and the cost overrun assess how the introduction of open auctions affects the actual procurement costs and ex post efficiency.

We have two measures of the quality of work as follows. The delay in completion is constructed

[14] Under scoring auctions with open bidding, engineers in the Kanto, which has jurisdiction over a large market, possibly bear large operational costs to review design proposals within a given period of time because it sometimes happens that more than 50 firms show their interest for a certain contract and submit design proposals. However, the extremely large number of participants is unlikely to occur in Shikoku which has jurisdiction over a small market. Hence, we consider that the timing of expanding scoring auctions with open bidding is earlier for Shikoku compared with Kanto and Kyushu.

[15] We dropped data which does not provide information on the quality score of work, the actual time to complete the work and the quality score of work. The rate of removed data is 5% or less.

as the difference (in days) between the actual time to complete the work and the contractual time to complete the work divided by the contractual time to complete the work. This variable measures the quality of work quantitatively.[16] The quality score of work measures the quality of work qualitatively and comprehensively because it includes information on the performance of the work besides information on the schedule control.

We classify the three work projects to define new participants and construct project type dummies for estimations. We use the data of general civil engineering work, maintenance and rehabilitation work and asphalt paving work. We classify general civil engineering work into three project types: road construction works, river works and bridge construction works. For maintenance and rehabilitation work, we construct three groups: road maintenance and rehabilitation, river works and bridge maintenance and rehabilitation. We then have seven project types. Based on the classification of the project types, we create project-type dummies.

Finally, for our empirical analysis, we provide a specific definition of new participants in open auctions based on the project types defined above.[17] We define firms which are only observed in the sample of open auctions as new participants in open auctions. Those firms submit their initial bids in open auctions through their voluntary participation, while they are not selected in invited auctions. Firms, which participate in open auctions more than twice in the period of our analysis, are still treated as new participants. New participants are defined in the seven project types respectively. The definition of the new participants is graphically illustrated in Figure 3.

2.4 Summary Statistics

Table 2 presents summary statistics of the procurement outcomes for Kanto (August 2006 − March 2007 and April 2007 − November 2007), Shikoku (November 2005 − March 2006 and April 2006 − August 2006) and Kyusyu (April 2006 − August 2006 and April 2007 - August 2007).[18] The data of the procurement outcomes shown in the table is broken out by the timing of the complete shift to open auctions for contracts with a certain range of the size of a contract. The table shows information on the relative winning bid, the relative final payment, the cost overrun, the delay in completion and the quality score of work. The relative winning bid and the relative final payment enable us to perform

[16]This quality measure is also used in Lewis and Bajari (2011) and Decarolis (2014).

[17]When we define new participants, we do not take joint ventures into account.

[18]For Shikoku, we observe four price-only auctions with invited bidders in the period between November 2005 and March 2006. For Kyushu, two price-only auctions with invited bidders are used in the period between April 2006 and August 2006 and only a price-only auction with invited bidders is used in the period from April 2007 to August 2007. However, two contracts were recognized as special cases to cope with emergency in disasters. With regard to Kanto, we find 3% of price-only auctions with invited bidders from August 2006 to March 2007 and seven of invited auctions between April and November in 2007. We drop these observations when conducting estimations.

direct comparisons of the winning bid (the final payment) across contracts of different sizes.

In Shikoku, the average winning bid is smaller under open auctions compared with invited auctions, but in Kanto and Kyushu, the average winning bid under invited auctions is slightly larger than that under open auctions.

The average final payment is much smaller under open auctions compared with invited auctions for Shikoku and Kyushu. With regard to Kanto, the average final payment is larger under open auctions compared with invited auctions. In particular, for Kyushu, the cost overrun is substantially decreased under open auctions compared with invited auctions.

The completion time is faster under open auctions than under invited auctions in Kanto and Shikoku. However, Kyushu shows the opposite result to Kanto and Shikoku. With respect to the quality score of work, there is not much difference between both auctions across the three regional bureaus.

Table 3 indicates that in invited auctions, only particular firms are repeatedly selected by officials in the regional bureaus, but in open auctions, new participants submit their bids. The number of responsible firms is publicly announced across each work project. As shown in Table 3, comparing Column (3)-(5) with Column (8), we find only less than 50% of responsible bidders were selected in invited auctions. Column (7) shows the presence of new participants, while the number of new participants is smaller than the total number of invited bidders. Moreover, we find that there is room to allow a number of firms to submit bids in invited auctions. This situation is particularly true of general civil engineering work and maintenance and rehabilitation work. Multiplying the number of invited auctions by the average number of potential bidders, we find that this number is much larger than the number of responsible bidders and the total number of invited bidders. For example, for road construction work in general civil engineering work in Kanto, about 3500 firms could have participated in invited auctions because the number of invited auctions is 350 and about 10 firms are invited in an invited auction, but the number of invited firms is merely 629, which is far less than the number of responsible bidders (1636). Hence, we find that only particular firms are allowed to make bids in invited auctions.

3 Empirical Model

In this section, we evaluate the quantitative performance of open auctions in comparison with invited auctions in terms of procurement costs and the quality of work. We predict that open auctions enhance competition through voluntary participation of efficient bidders. Furthermore, the theoretical auction literature shows that scoring auctions give incentives for contractors to exploit their expertise about construction practices and improve the performance of construction works. However, a concern in the scoring auction is that under a scoring design, open auctions possibly end up as de fact invited auctions due to the manipulation of evaluations of documents related to the quality of work. It is uncertain whether open auctions under the scoring design lead to aggressive bidding due to the presence of the counteracting effects. Hence, we investigate whether open auctions under the scoring design work well or not in terms of not only the winning bid but also ex post performance including the final payment and the quality of work.

We estimate the effects of open auctions on contracts which were awarded through invited auctions. Therefore, we estimate the following model,

$$Y_{at} = \alpha_1 + \alpha_2 D_{at} + X'_{at}\alpha_3 + \tilde{\epsilon}_{at} \tag{1}$$

The dependent variable Y_{at} is the relative winning bid, the relative final payment, the cost overrun, delay in the completion or the quality score of work. In this estimation model, D_{at} takes 1 when a contract at auction a in time period t is awarded through an open auction and 0 otherwise. X'_{at} includes the auction-level characteristics, project type dummy, business environment, geological and meteorological conditions variables at auction a in time period t. The estimates of the coefficient α_2 are our main interest and capture the impacts for introduction of open auctions on contracts which were procured through invited auctions.

The summary statistics provide clear differences between open and invited auctions in Shikoku and Kyushu, but they are not formal statistical inference. When invited auctions were used, the government possibly engaged in selecting firms with technical advantages of improving the quality levels or firms which make corrupt payments. Open auctions may be used to promote the participation of new efficient firms with cost advantages and exclude inefficient firms which pay bribes to officials in the regional bureau. These unobserved factors are possibly correlated with the choices of the auction methods in the estimation model. In this case, OLS causes biases in the estimates of α_2. To circumvent this, the policy change of auctions triggered by the revelation of large-scale collusion is used as an instrument variable because the introduction of open auctions by the exposure of the collusion is unrelated to the expected effects of open auctions for officials in the regional bureaus. Moreover, arguably, the differences of the timing of the introduction of open auctions are not related to the effects of open auctions because they are affected by the operational costs and work volume. Hence, we identify the causal effect of the introduction of open auctions by relying on IV estimates. There are single instrument and one endogenous treatment variable. The first stage equation is given by:

$$D_{at} = \beta_1 + \beta_2 Z_t + X'_{at}\beta_3 + \epsilon_{at} \tag{2}$$

In this estimation model, the variable Z_t represents the policy change and takes the value 1 when the outcome of procurement is observed in 2006 and 0 otherwise for the estimations in Shikoku. For estimations in Kanto and Kyushu, this variable takes the value 1 if the procurement outcome is observed in 2007 and 0 otherwise. The estimation model is specified at auction a in time period t. The covariates in this regression model (X'_{at}) are the same as those used in the second stage regression.

3.1 Variable Definitions

We provide the definitions of independent variables. There are three kinds of control variables: auction-level characteristics, natural environment characteristics and business environments characteristics.

There are five auction-level characteristics: the log of the reserve price, the log of the contractual time, the number of potential bidders and project type dummies. The log of the reserve prices and the log of the contractual time control for the difference in the size of a contract across auctions. The number of potential bidders controls for differences in competition across auctions. We present the definitions of number of potential bidders for both auctions. In this paper, we define two types of potential bidders in invited and open auctions respectively. In the invited auction, potential bidders are treated as bidders who are selected by the government for a certain project, while actual bidders are treated as bidders who eventually submit their bids. In the open auction, potential bidders are defined as bidders who show their interests for a certain project and satisfy the minimum requirements, while actual bidders are defined as bidders who eventually place bid. In addition to these variables, we create project-type dummies based on the classification of the project types.[19]

We provide four variables to control for geological conditions that change across project sites. We construct the variables of the conditions of surface ground, faults, landslides and liquefaction. We also present the two measures of meteorological conditions which differ across project sites: the amount of rainfall and the minimum temperature. In public-works construction, these factors have influence on both of the final payments and the quality of work due to the moral hazard problem and adaptation costs through contractual incompleteness. We describe the detailed information on the construction of the variables in the Appendix.

[19] In the data, port construction work and miscellaneous work are included. However, we drop the data of these projects because it accounts for less than 0.5% of the entire data.

We have four variables to control for the difference in business conditions across project sites: the construction materials prices, the income level and monthly dummies. These variables control for factors that change over time other than the policy of auction methods. The Appendix shows the definitions of these variables.

4 Empirical Evidence on the Impacts of Open Auctions

4.1 Testing for Assumptions

We diagnose whether the instrument (Z_{at}) is valid or not. To check whether the exclusion restriction is satisfied or not, we analyze the differences in economic environments and potential participants in procurement between the two periods: before and after the timing of the complete shift to open auctions. That is because we compare procurement outcomes before and after the policy change. The estimation results using the empirical model are possibly affected by unobserved differences in business environments and potential participants between the two periods. Hence, we investigate the comparisons of the number of responsible bidders and business environments before and after the timing of the complete switch to open auctions.

We are concerned that the introduction of open auctions may reduce the number of potential firms in the markets due to the intensification of competition and the shake-out of inefficient firms.[20] Column (4) and (5) of Table 3 show that decline in the number of responsible bidders does not occur in the period from 2006 to 2007 in Kanto. In contrast to Kanto, Column (3) and (4) of Table 3 indicate that the number of responsible bidders falls by about 20% from 2005 to 2006 in Shikoku. However, we consider that this is not problematic for Shikoku, because the period for the analysis is not long. For Kyushu, as Column (4) and (5) of Table 3 shows, the number of responsible bidders increases by about 15% from 2006 to 2007.

For business environments, Table 4 indicates the differences in the unemployment rate and the average income per taxpayer before and after the timing of the complete shift to open auctions.[21] For Kanto, the unemployment rate is 3.53% and the average income per taxpayer is 3359671 in 2006 and the unemployment rate is 3.32% and the average income per taxpayer is 3368993 in 2007. Hence, for the economic environments, there is not much different between the two periods in Kanto. For Shikoku, the unemployment rate is 3.58% and the average income per taxpayer is 2872120 in

[20]One may be concerned that firms which are located in a region with early introduction of open auctions move to the other region where invited auctions are still implemented. According to people in the construction industry, construction firms cannot move to other regions easily when competition intensifies in their territories because they do not have connections to subcontractors in other regions which have thorough knowledge of geological conditions at project sites.

[21]For the unemployment rate, see http://www.stat.go.jp/data/roudou/pref/.

2005 and the unemployment rate is 3.38% and the average income per taxpayer is 2819944 in 2006. Hence, for Shikoku, there is not much difference in the unemployment rate and the average income per taxpayer between the two periods. With regard to Kyushu, the unemployment rate is 4.41% and the average income per taxpayer is 2745017 in 2006 and the unemployment rate is 3.89% and the average income per taxpayer is 2683509 in 2007. Hence, there are changes for the unemployment rate between the two distinct periods for Kyushu.

In summary, based on the evidence, in Kanto, potential participants in the procurement and the business environments are the same in the periods for our analysis. Hence, we assume that the requirements for the exclusion restriction are satisfied for the estimation model used for Kanto. With regard to Shikoku, the business environments are the same between the periods, while the potential participants may be slightly different. However, in particular, in Kyushu, potential participants may be different between the two periods because several (in)efficient firms possibly enter the market in 2007. In addition, for Kyushu, the differences in the business environments between the two periods arise, while the effects may not be large because the sample used for our analysis is before economic downturn precipitated by the Lehman Brothers bankruptcy in 2008. This problem may cause possible biases to estimate the treatment effect. Hence, to deal with the unobserved shocks between the two periods, we shorten the periods for our analysis and conduct the DID analysis for robustness of our estimates.

4.2 Testing for the Manipulations of Project Sizes

We care about endogeneity in the size of a project when performing estimations. The size of a project in invited auctions may be smaller compared with open auctions because it is possible that officials in the government deliberately divide contracts into small-scale ones to use invited auctions for the selections of bribe-paying firms which are not necessarily efficient. Mauro (1998)'s empirical finding shows that corruption causes the distortion of the government expenditures. Hence, invited auctions may lead to inefficient outcomes and high procurement costs through the distortion of the size of a project. This also introduces possible bias in IV and OLS estimates.

Figure 4-6 display the distributions of reserve prices for all regional bureaus in the period of our analysis. We expect that the number of small-scale contracts to the total number of contracts would be larger when invited auctions were dominant. With regard to Kanto, the reserve prices are slightly larger from April 2007 to November 2007 compared with August 2006 to March 2007, but the proportion of contracts with the value of a reserve price JPY 300 million yen to the total contracts is larger from August 2006 to March 2007. For Shikoku, the reserve prices tend to be larger in the period in which invited auctions were used. Hence, we consider that the distortion of the size of a project is not serious for Kanto and Shikoku. For Kyushu, the proportion of contracts with the value of a reserve price from JPY 100 to 200 million remains unchanged between 2006 and 2007, but the proportion of contracts with the value of a reserve price below JPY 50 million yen is larger from April 2006 to August 2006. Hence, for Kyushu, the distortion of the size of a project may arise.

We are also concerned that large amounts of contracts that would have been awarded through open auctions in 2007 were divided into small-scale contracts and procured through invited auctions in 2005 and 2006. However, the spending for public-works procurement held by eight regional bureaus amount to JPY 1.17 trillion (11663 contracts) in 2005, JPY 1.27 trillion (11733 contracts) in 2006 and JPY 1.48 trillion (11243 contracts) in 2007.[22] The evidence shows that the spending in 2005 is smaller that in 2007 and the number of contracts differs by merely 4%. Hence, this allows us to assume that the big shifts in the procurement of contracts did not occur.

As Table 4 shows, for Shikoku, the number of contracts is the same between November 2005 − March 2006 and April 2006 − August 2006. However, for Kanto, the number of contracts awarded between April 2007 and November 2007 is smaller compared with between August 2006 and March 2007. Kyushu shows the same pattern. Hence, we are concerned that big shifts in the procurement of contracts arise to use invited auctions in Kanto and Kyusyu. For Kanto, comparing August 2005 − March 2006 with April 2006 − November 2006, the ratio of contracts with a reserve price from JPY 100 to 200 million awarded between August 2005 and March 2006 is 34% ($= \frac{238}{(453+238)}$) and the ratio between August 2006 and March 2007 is 34% ($= \frac{201}{(386+201)}$) which is shown in Table 4. For Kyushu, the number of contracts awarded from April 2005 to August 2005 is 72, while as indicated in Table 4, the number of contracts awarded from April 2006 to August 2006 is 113. Hence, the number of contracts is smaller in the period in which invited auctions were dominant. The evidence also allows us to assume that the big shifts of the procurement of contracts for the usage of invited auctions did not arise for individual regional bureau.

4.3 Estimation Results on the Introduction of Open Auctions

In this section, we estimate the effects of open auctions on the winning bid, the final payment, the cost overrun, the completion time and the quality score of work by relying on the IV method. Table 5 reports the estimation results of introducing open auctions on the relative winning bid, the relative final payment and the cost overrun in the three samples (i.e. Kanto, Shikoku and Kyushu). Table 6

[22]For information on the spending for public-works procurement held by eight regional bureaus, see http://www.mlit.go.jp/chotatsu/contractsystem/keiyaku/.

reports the estimation results for introducing open auctions on the delay in completion and the quality score of work in the three samples.

We check whether the variable D_{at} representing the auction methods is sufficiently correlated with the proposed instrumental variable Z_t (*year*). Column (1) and (6) of Table 5 and column (1) and (4) of Table 6 show that the coefficients on *year* are highly significant with a F-statistics of over 10. The coefficients in estimates for Kanto and Shikoku indicate that in 2006 (2007), the number of open auctions sharply increases. However, for Kyushu, the correlation between D_{at} and Z_t appears to be lower with a t-statistics of about 4, while the F-statistics is more than 100. In the following, we use the instrument variable to estimate the causal effect of introducing open auctions on the contracts which were awarded through invited auctions.

In column (3), (5) and (8) of Table 5, we report the IV estimates of the effects of switching from invited auctions to open auctions on the winning bid, the final payment and the cost overrun. For Kanto, the introduction of open auctions reduces the relative final payment declines by 9% and the cost overrun by 12% with a t-statistics of -1.62, while it does not affect the winning bid. The estimation results for Shikoku indicate that the switch to open auctions leads to the significant decline in the final payments by 28% and the cost overruns by 26% despite that the winning bid does not fall. For Kyushu, the estimation results are similar to Kanto and Shikoku, but the magnitude of the coefficient is strikingly large. The final payment falls by 126% and the cost overrun by 109% through the policy change, but the winning bid is not affected by the policy change. These results indicate that the introduction of open auctions does not reduce the winning bid, but it leads to the reduction in the final payment and the cost overrun.

Column (3) and (6) of Table 6 show the IV estimates of the impacts of introducing open auctions on the delay in completion and the quality score of work. For Kanto, the delay in completion improves by 68% due to the policy change. In spite of the results, the switch to open auctions does not worsen the quality score of work. The results for Shikoku indicate that the policy change leads to decline in the delay in completion by 70%, but it does not lower the quality score of work. For Kyushu, the magnitude of the coefficient is strikingly large and the delay in completion is decreased by 347%. However, the quality score of work is not affected by the policy change. The estimation results shows that the introduction of open auctions decreases the completion time, but it does not worsen the quality score of work.

The results for OLS estimates are reported in Column (2), (4) and (7) of Table 5 and Column (2) and (5) of Table 6. We find that the effects of introducing open auctions reported in OLS estimates are different from the results reported in the IV estimates. However, the OLS results do not provide the causal effects of introducing open auctions on contracts which were procured by invited auctions because unobserved factors affecting the efficiency of potential participants in the procurement are likely to influence the outcomes of procurement. Hence, we consider that the IV results are plausible.

We discuss the reasons why open auctions lead to the decline in the final payment and the cost overrun, but it does not in the winning bid. We consider that the presence of appraisal values may not reduce the winning bids. Even if the winning bids are lower than the appraisal values, the bids are not necessarily rejected. However, bidders may consider the presence of the appraisal value and the rejection of their bids when developing bidding strategies. Hence, the efficiency levels and competitive pressures are not sufficiently reflected to the winning bids, but they are reflected to the final payments, the cost overruns and the completion time. Moreover, competitive pressures for design proposals in scoring auctions with open bidding can lead to the reduction in the completion time and the cost overruns because scoring auctions can give incentives for contractors to exploit their practical skills and expertise. Hence, the effects of open auctions are in response to the synergy between scoring auctions and the open auctions.

4.4 Robustness Checks

In this section, we change the periods of our empirical analysis for the robustness checks because the estimation results reported in the previous section may be affected by the unobserved differences in competitive environments and unobserved macroeconomic shocks before and after the timing of the complete shift to open auctions. Hence, we shorten the periods for our analysis: Kanto (September 2006 − March 2007 and April 2007 − October 2007), Shikoku (December 2005 − March 2006 and April 2006 − July 2006) and Kyusyu (April 2006 − August 2006 and April 2007 − August 2007).[23] The specification of the estimation model is the same as the empirical model used in the previous section.

Column (3), (5) and (8) of Table 7 report the IV estimates of the impacts of introducing open auctions on the winning bid, the final payment and the cost overrun. The first stage results indicate the same patterns as the results reported in Table 5. For Kanto, the switch to open auctions reduces the final payment by 12% and the cost overrun by 14%. The estimation results for Shikoku show that open auctions lead to the significant decline in the winning bid by 4.9%, the final payment by 36% and the cost overrun by 29%. With regard to Kyushu, the introduction of open auctions decreases the final payment by 60% and the cost overrun by 49% with a t-statistics of 1.66. Hence, the estimation

[23] We do not include the sample of maintenance and rehabilitation work for estimations in Kyushu because for the work project, there are no samples of open auctions.

results of Table 7 show the similar patterns to the results indicated in Table 5.

In column (3) and (6) of Table 8, we report the IV estimates of the effects of switching from invited auctions to open auctions on the delay in completion and the quality score of work. The first stage results show the same patterns as the results presented in Table 6. For Kanto, the delay in completion declines by 62% due to the switch to open auctions. For Shikoku, open auctions lead to the significant decline in the delay in completion by 58%. With regard to Kyushu, the introduction of open auctions reduces the delay in completion by 140%. However, the quality score of work is not affected by the policy changes across the regional bureaus. Hence, the results of Table 8 indicate the similar pattern to Table 6.

With regard to Kyushu, we also provide the DID estimations to compare open auctions with invited auctions for the robustness checks because the correlation between is lower compared with Kanto and Shikoku. Furthermore, the estimation results for Kyushu are possibly affected by unobserved macroeconomic shocks and unobserved differences in potential participants. For the DID analysis, the treatment group is Kyushu and the control group is Shikoku. The auction method was changed in September 2006 in Kyusyu, but in Shikoku, there was a uniform auction method between 2006 and 2007. In addition, Shikoku and Kyushu have similar geological and topographical features because they are mountainous areas.[24] They also have similar economic environments because both of them basically belong to rural areas in Japan. Hence, we divide the sample into two periods: the periods before and after April 2007 and exploit the data from April 2006 to August 2006 and April 2007 to August 2007. The DID analysis is performed at the auction-level. The estimation model is written in auction a in time period t.

$$Y_{at} = \beta_1 + \beta_2 D_t + \beta_3 T_t + \beta_4 (T_t \times D_t) + X'_{at}\beta_5 + \epsilon_{at} \tag{3}$$

The variable D_t takes 1 if procurement takes place in 2007 and 0 otherwise. The variable T_t takes 0 in Shikoku and 1 in Kyusyu. The dependent variables and the covariates in the estimation model are the same as those of the IV estimates. The coefficient β_4 is our main interest and measures the effect of introducing open auctions.

Table 9 reports the DID estimates of the impacts of introducing open auctions on the winning bid, the final payment and the cost overrun. The final payments decline by 12% and the cost overrun is reduced by 9.7%. Table 10 shows that open auctions lead to the significant decline in the delay in completion by 26.2%, but the worsening of the quality score of work does not arise. Hence, the results of Table 9 and 10 show the similar pattern to Table 5 and 6.

[24] In Shikoku, the size of a contract is larger in 2007 than in 2006.

4.5 Evidence on the Effects of New Participants

We investigate whether the presence of new participants enhances competition. In this section, we provide suggestive evidence on the effects of new participants in terms of procurement costs and the quality of work by using summary statistics and OLS.

Table 11 reports summary statistics on the relative winning bids, the relative final payments, the cost overrun, the delay in completion and the quality score of work for invited auctions and open auctions where new participants submit bids. We find that when new participants submit bids, the average final payment under open auctions is about 17% smaller than that under invited auctions in Kyushu. For Shikoku, compared with invited auctions, the final payment falls by 7% in open auctions where new participants submit bids. Kanto does not show the same tendency, but the completion time is improved by the presence of new participants. Shikoku also shows the delay in completion is reduced when new participants submit bids. However, the quality score of work is not worsened by the presence of new participants for all the regional bureaus.

We apply the OLS to estimate the effects of the new participants at the auction-level because we do not find an instrumental variable. The estimation model is given in auction a in time period t is specified by:

$$Y_{at} = \beta_1 + \beta_2 D_{at} + X'_{at}\beta_3 + u_{at} \tag{4}$$

where D_t takes 1 if new participants submit bids in an auction and 0 otherwise. The dependent variables and covariates in the estimation model are also the same as the IV estimates.

Table 12 indicates the OLS estimates of the effects of the presence of new participants on the winning bid, the final payment and the cost overrun. For Kanto, the presence of new participants does not affect the winning bid, the final payment and the cost overrun. The results for Shikoku indicate that the presence of new participants reduces the winning bid by 3.5%, but it does not affect the final payment and the cost overrun. For Kyushu, when new participants submit bids, the relative final payment and the cost overrun falls, while they are not significant. When we use the log of the final payment, the final payment is reduced by 7.6% through the presence of new participants.

Table 13 shows the OLS estimates of the impacts of the presence of new participants on the delay in completion and the quality score of work. With regard to Kanto, the presence of new participants reduces the delay in completion. The results for Shikoku indicate that the presence of new participants does not affect the delay in completion. For Kyushu, the completion time is increased by the presence of new participants. However, the presence of new participants does not worsen the quality score of work.

The evidence on new participants suggests that the presence of new participants tends to reduce the procurement costs, while it does not affect the quality score of work. The results suggest that the effects of introduction of open auctions arise through different process. For Kanto, competitive pressures for incumbent bidders seem to come from the uncertainty that they do not know which firms are potential bidders. However, for Shikoku and Kyushu, the behavior for incumbents may be directly influenced by the presence of new participants.

5 Conclusion

Market entry regulations are common worldwide. In public procurement, the government regulates entry through invited auctions because it is concerned with procurement costs and the quality of work. Invited auctions possibly cause high procurement costs through bidding rings and the selections of particular (inefficient) firms, but the government seems to believe that invited auctions are effective to ensure the quality of work by excluding firms with low technology levels prior to auction. Although open auctions induces large participation in a market and increase competition, new participants may worsen the quality of work due to their insufficient experience. This paper quantifies the impacts of open auctions over invited auctions to investigate whether relaxing entry regulations is beneficial for the government or not. The nationwide policy change and data including information on ex post performance in Japan enable us to quantify the benefits of open auctions over invited auctions under a scoring design with respect to not only the winning bids but also the final payments and the quality of work.

Our estimation results show that the introduction of open auctions reduces final payments by about 10% or more and decreases the completion time 20% or more. Despite that, the results on the quality score of work do not indicate the worsening of the quality of work which consists of information on the performance of the work and the completion time. We use three regional bureaus for our empirical analysis, but the estimation results and economic implications are the same across the regional bureaus. If we change the periods used for our analysis, the estimation results remain unchanged. The results of the DID analysis also present the same results as those of the IV methods. Hence, our results are robust.

A policy suggestion for our estimation results is that the introduction of open auctions under scoring designs is beneficial for the government because it reduces the procurement costs without worsening the quality score of work. However, it is possible that the government wishes to use entry regulations for the reduction of the dispersion of the quality levels and its payoff because its preference may be risk averse. Since the empirical research is beyond the scope of this paper, we leave the identification and estimation of the government's risk preference to future research.

6 Appendix

We describe the definitions of the variables of geological conditions around the project sites. The variables of geological conditions are constructed based on the GIS (Geographic Information System) data for geology produced by Wakabayashi, Matsuoka, Kubo, Hasegawa and Sugiura (2005) and data for geological conditions and faults publicly available from the MLIT website.[25] The GIS data is the data of 1 kilometer mesh data and it is constructed based on AVS30 that is the index of susceptible surface ground conditions by earthquakes at a site.[26]

There are four geological factors that have influence on the execution of public-work projects according to Ikeda (1986): the condition of surface ground, the condition of faults, the condition of landslides and the condition of liquefaction. According to Ikeda (1986), when the project site is geologically complex, the initial specifications and plans tend to be substantially modified. We construct the variables of the conditions of surface ground and liquefaction by using the data of Wakabayashi et el. (2005). We construct the variables of the conditions of landslides and faults at the project site by exploiting information on geological conditions affecting landslides and faults. The variable of the condition of surface ground represents the surface geological condition within 1 kilometer radius of the project site. This variable is negatively correlated with the softness of surface ground. This variable takes from 100 (bad surface ground condition) to 740 (good surface ground condition). The variable of faults measures the condition of faults within 1 kilometer radius of the project site. This variable takes from 0 (no risk from faults) to 1 (high risk from faults). In Japan, landslides are mainly caused by the geological conditions of Neogene period including green tuff and serpentine. This variable also takes from 0 (no risk for landslides) to 1 (high risk for landslides). The variable of landslides represents whether the area within 1 kilometer radius of the project site is affected by geological factors which cause landslides. The variable of liquefaction measures the condition of liquefaction within 1 kilometer radius of the project site. This variable takes from 1 (high risk from the liquefaction) to 4 (low risk from the liquefaction). When projects are performed at several points, we take the average of the values of geological conditions.

We show how to construct the variables of meteorological conditions around the project sites.[27] In Japan, there are totally about 1000 meteorological observatories. We use the data which is the closest observatory to the project site. The variables of meteorological condition are constructed using publicly available data from the Japan Meteorological Agency website. The data is monthly data. The variable of the amount of rainfall represents the average amount of rainfall around the

[25] The data of landslides and faults is available from http://nrb-www.mlit.go.jp/kokjo/inspect/landclassification/download/.
[26] This data is also used to construct a map for measures to deal with earthquake by the Cabinet office.
[27] See http://www.data.jma.go.jp/obd/stats/etrn/.

project site in each year. The variable of minimum temperature is the minimum temperature around the project site in each year. For projects covering several points, we take the average of the values of meteorological conditions.

We explain the variables of business environments around the project sites: the construction materials prices, the unemployment rate and the income level. The variable of construction materials prices consists of ten kinds of representative construction materials prices used to perform tasks.[28] The data of construction materials prices is composed of the prices of steel, the secondary product of concrete, fresh concrete, cement, aggregate, asphalt mix, bituminous material, special steel and temporary material. This data is monthly calculated based on Paasche index of these prices and constructed at each regional bureau level. We use the material price recorded at the month of completion of work for our analysis. The variable of the unemployment rate is constructed by the data of unemployment rate recorded in about 1800 cities in 2005. The variable of the income level is measured on the basis of the data of the average annual income per taxpayer at about 1800 cities. In order to construct this variable, we use the data of the city that is the nearest to the project location. For projects covering several project locations, we use the average values of economic environments at project locations.

[28]For the construction materials prices, we use the data constructed by Economic Research Association. The data of the income level is obtained from the data of population and households provided by Statistical Bureau.

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Table 1: The Operational Costs and the Transition of Scoring Auctions with Open Bidding

	(1)	(2)	(3)	(4)	(5)	(6)
Regional bureau	Budget size per official	Percentage of engineers (in 2004)	Number of contracts per engineer (in 2004)	Expansion of open auctions 2005.4−2006.3 Percentage of open auctions	2006.4−2007.3 Percentage of open auctions	2007.4−2008.3 Percentage of open auctions
Tohoku	262.34	61.52	0.96	0.11	0.88	0.99
Kanto	516.62	62.99	1.19	0.08	0.28	0.81
Hokuriku	250.52	61.73	0.92	0.23	0.95	0.95
Chubu	377.57			0.16	0.76	1.00
Kinki	525.85			0.03	0.61	0.96
Chugoku	356.92	62.75	1.25	0.07	0.64	0.94
Shikoku	249.47	61.44	0.94	0.13	0.99	1.00
Kyushu	336.54	61.59	1.31	0.03	0.71	0.96

Note: The information on the percentage of engineers and the number of contracts per engineer comes from the survey data of Nikkei Construction (2005). For information on the budget sizes (in 2005) and the number of officials (in 2007), see http://www.cao.go.jp/bunken-kaikaku/iinkai/kaisai/dai33/33shiryou2.pdf. When any information is not reported, we use blank columns. In this table, we leave out information on contracts worth JPY 720 million or more.

Table 2: Summary Statistics

Kanto	Invited	Open
Variable	Mean Standard deviation	Mean Standard deviation
Relative winning bid	0.87	0.89
	(0.10)	(0.07)
Relative final payment	1.07	1.11
	(0.27)	(0.32)
Cost overrun	0.23	0.24
	(0.27)	(0.32)
Quality score of work	74.70	74.85
	(5.13)	(4.36)
Delay in completion	0.68	0.33
	(2.69)	(0.53)
Sample size	300	287

Shikoku	Invited	Open
Variable	Mean Standard deviation	Mean Standard deviation
Relative winning bid	0.94	0.92
	(0.04)	(0.06)
Relative final payment	1.17	1.13
	(0.22)	(0.17)
Cost overrun	0.24	0.23
	(0.21)	(0.17)
Quality score of work	74.84	74.63
	(3.95)	(4.53)
Delay in completion	0.32	0.13
	(0.36)	(0.21)
Sample size	38	99

Kyushu	Invited	Open
Variable	Mean Standard deviation	Mean Standard deviation
Relative winning bid	0.87	0.88
	(0.08)	(0.08)
Relative final payment	1.28	1.13
	(0.45)	(0.31)
Cost overrun	0.46	0.29
	(0.44)	(0.31)
Quality score of work	74.17	75.13
	(2.83)	(3.48)
Delay in completion	0.11	0.31
	(0.24)	(0.43)
Sample size	41	151

Note: Robust standard deviations are in parentheses.

Table 3: The Environment for Competition in Auctions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Kanto	Number of open auctions in 05−07	Number of invited auctions in 05−07	Number of responsible bidders in 05	in 06	in 07	Ave number of invited bidders in each invited auction	Number of new participants	Total number of invited bidders
Road c	194	350	1636	1294	1293	9.2	51	629
River c	203	426	1636	1294	1293	9.8	38	534
Bridge c	119	112	1636	1294	1293	8.9	62	313
Paving A	183	190	40	35	35	10	8	70
Paving B	44	127	560	409	408	9	8	238
Road m & r	182	437	4986	4286	4496	8.5	17	848
River m & r	188	536	4986	4286	4496	9.9	23	813
Bridge m & r	75	101	4986	4286	4496	7.9	27	219
Shikoku								
Road c	204	68	633	490	497	10.5	27	189
River c	216	83	633	490	497	10.4	36	176
Bridge c	67	25	633	490	497	10.4	42	117
Paving A	84	15	21	24	24	11.7	1	16
Paving B	39	10	217	187	198	7.6	8	32
Road m & r	174	83	2400	2071	2177	9.8	20	212
River m & r	57	28	2400	2071	2177	10	25	169
Bridge m & r	44	14	2400	2071	2177	10.5	31	75
Kyushu								
Road c	418	224	931	694	807	11.6	59	436
River c	446	252	931	694	807	11.4	74	419
Bridge c	274	100	931	694	807	11.1	90	322
Paving A	120	46	40	41	43	15.3	18	35
Paving B	122	70	344	252	284	10.9	47	177
Road m & r	280	335	5664	4829	5367	9.5	89	766
River m & r	244	476	5664	4829	5367	9.3	83	860
Bridge m & r	62	42	5664	4829	5367	9.4	49	222

Note: “road c” denotes road construction works, “river c” denotes river construction works and “bridge c” denotes bridge construction works in general civil engineering work. “road m & r” represents road maintenance & rehabilitation, “river m & r” denotes river works in maintenance & rehabilitation and “bridge m & r” denotes bridge maintenance & rehabilitation. “Paving A” represents asphalt paving work worth more than JPY 120 million when the government awards a contract. “Paving B” denotes asphalt paving work worth from JPY 50 million to JPY 120 million when the government procures a contract. For information on the number of responsible bidders, see http://www.mlit.go.jp/chotatsu/contractsystem/keiyaku/.

Table 4: Differences of Environments for Auctions between Two Periods

Kanto	2006	2007
Variable	Mean Standard deviation	Mean . Standard deviation
Unemployment rate	3.53	3.32
	(0.42)	(0.37)
Income	3359671	3368993
	(751138)	(609232)
Sample size	386	201

Shikoku	2005	2006
Variable	Mean Standard deviation	Mean . Standard deviation
Unemployment rate	3.58	3.38
	(0.31)	(0.27)
Income	2872120	2819944
	(268522)	(241759.8)
Sample size	68	69

Kyushu	2006	2007
Variable	Mean Standard deviation	Mean . Standard deviation
Unemployment rate	4.41	3.89
	(0.72)	(0.79)
Income	2745017	2683509
	(295066.5)	(296127.1)
Sample size	113	79

Note: Robust standard errors are in parentheses.

Table 5: Estimation results for the Procurement Costs

A. Kanto	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Open	Relative winning bid	Relative winning bid	Relative final payment	Relative final payment	Open	Cost overrun	Cost overrun
Estimator	First-stage OLS	OLS	IV	OLS	IV	First-stage OLS	OLS	IV
Year	0.904***					0.905***		
	(0.038)					(0.039)		
F-first stage	211.41					202.14		
Open		0.014*	0.019	0.024	-0.091		0.004	-0.123**
		(0.008)	(0.014)	(0.038)	(0.056)		(0.037)	(0.054)
R-squared		0.2352		0.166			0.160	
Sample size	587	587	587	587	587	587	587	587

B. Shikoku	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Open	Relative winning bid	Relative winning bid	Relative final payment	Relative final payment	Open	Cost overrun	Cost overrun
Estimator	First-stage OLS	OLS	IV	OLS	IV	First-stage OLS	OLS	IV
Year	0.886***					0.888***		
	(0.159)					(0.161)		
F-first stage	27.24					26.19		
Open		-0.042***	-0.010	-0.088	-0.275**		-0.031	-0.263*
		(0.014)	(0.030)	(0.058)	(0.132)		(0.061)	(0.142)
R-squared		0.351		0.210			0.149	
Sample size	137	137	137	137	137	137	137	137

C. Kyushu	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Open	Relative winning bid	Relative winning bid	Relative final payment	Relative final payment	Open	Cost overrun	Cost overrun
Estimator	First-stage OLS	OLS	IV	OLS	IV	First-stage OLS	OLS	IV
Year	0.204***					0.205***		
	(0.064)					(0.064)		
F-first stage	190.21					181.42		
Open		0.013	-0.181	0.032	-1.257**		0.012	-1.087*
		(0.020)	(0.116)	(0.080)	(0.603)		(0.078)	(0.566)
R-squared		0.234		0.284			0.240	
Sample size	192	192	192	192	192	192	192	192

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are presented in the right of the coefficients. All regressions include a constant term, the auction-level characteristics, the variables of geological conditions, meteorological conditions, economic environments and monthly dummy variables. The log of the reserve price is excluded for estimations on the relative winning bid (final payment). The log of the contractual time is excluded for estimations on the delay in completion.

Table 6: Estimation results for the Quality of Construction Works

A. Kanto	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Open	Delay in completion	Delay in completion	Open	Log of quality score	Log of quality score
Estimator	First-stage OLS	OLS	IV	First-stage OLS	OLS	IV
Year	0.881***			0.905***		
	(0.041)			(0.039)		
F-first stage	226.33			202.14		
Open		-0.526**	-0.678***		0.001	0.004
		(0.226)	(0.145)		(0.007)	(0.012)
R-squared		0.04			0.078	
Sample size	587	587	587	587	587	587

B. Shikoku	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Open	Delay in completion	Delay in completion	Open	Log of quality score	Log of quality score
Estimator	First-stage OLS	OLS	IV	First-stage OLS	OLS	IV
Year	0.793***			0.888***		
	(0.163)			(0.161)		
F-first stage	32.52			26.19		
Open		-0.227***	-0.698***		0.011	0.010
		(0.083)	(0.235)		(0.016)	(0.031)
R-squared		0.352			0.186	
Sample size	137	137	137	137	137	137

C. Kyushu	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Open	Delay in completion	Delay in completion	Open	Log of quality score	Log of quality score
Estimator	First-stage OLS	OLS	IV	First-stage OLS	OLS	IV
Year	0.212***			0.205***		
	(0.064)			(0.064)		
F-first stage	186.42			181.42		
Open		0.070	-3.467**		0.013	0.018
		(0.076)	(1.398)		(0.012)	(0.082)
R-squared		0.225			0.215	
Sample size	192	192	192	192	192	192

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are presented in the right of the coefficients. All regressions include a constant term, the auction-level characteristics, the variables of geological conditions, meteorological conditions, economic environments and monthly dummy variables. The log of the reserve price is excluded for estimations on the relative winning bid (final payment). The log of the contractual time is excluded for estimations on the delay in completion.

Table 7: Robustness Checks for the Procurement Costs

A. Kanto	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Open	Relative winning bid	Relative winning bid	Relative final payment	Relative final payment	Open	Cost overrun	Cost overrun
Estimator	First-stage OLS	OLS	IV	OLS	IV	First-stage OLS	OLS	IV
Year	0.877***					0.877***		
	(0.041)					(0.042)		
F-first stage	267.52					255.24		
Open		0.013	0.017	0.037	-0.115*		0.021	-0.140**
		(0.009)	(0.016)	(0.042)	(0.067)		(0.042)	(0.065)
R-squared		0.213		0.172			0.172	
Sample size	542	542	542	542	542	542	542	542

B. Shikoku	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Open	Relative winning bid	Relative winning bid	Relative final payment	Relative final payment	Open	Cost overrun	Cost overrun
Estimator	First-stage OLS	OLS	IV	OLS	IV	First-stage OLS	OLS	IV
Year	0.895***					0.893***		
	(0.157)					(0.159)		
F-first stage	21.51					20.28		
Open		-0.049***	-0.055*	-0.116*	-0.358***		-0.049	-0.294**
		(0.014)	(0.030)	(0.059)	(0.127)		(0.063)	(0.137)
R-squared		0.342		0.198			0.134	
Sample size	103	103	103	103	103	103	103	103

C. Kyushu	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Open	Relative winning bid	Relative winning bid	Relative final payment	Relative final payment	Open	Cost overrun	Cost overrun
Estimator	First-stage OLS	OLS	IV	OLS	IV	First-stage OLS	OLS	IV
Year	0.419***					0.423***		
	(0.100)					(0.102)		
F-first stage	4.35					4.06		
Open		0.004	-0.078	0.057	-0.600*		0.056	-0.489
		(0.022)	(0.079)	(0.109)	(0.323)		(0.110)	(0.295)
R-squared		0.329		0.330			0.277	
Sample size	82	82	82	82	82	82	82	82

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are presented in the right of the coefficients. All regressions include a constant term, the auction-level characteristics, the variables of geological conditions, meteorological conditions, economic environments and monthly dummy variables. The log of the reserve price is excluded for estimations on the relative winning bid (final payment). The log of the contractual time is excluded for estimations on the delay in completion.

Table 8: Robustness Checks for the Quality of Construction Works

A. Kanto	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Open	Delay in completion	Delay in completion	Open	Log of quality score	Log of quality score
Estimator	First-stage OLS	OLS	IV	First-stage OLS	OLS	IV
Year	0.851***			0.877***		
	(0.044)			(0.042)		
F-first stage	339.86			255.24		
Open		-0.495*	-0.624***		0.009	0.014
		(0.259)	(0.177)		(0.008)	(0.014)
R-squared		0.040			0.081	
Sample size	542	542	542	542	542	542

B. Shikoku	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Open	Delay in completion	Delay in completion	Open	Log of quality score	Log of quality score
Estimator	First-stage OLS	OLS	IV	First-stage OLS	OLS	IV
Year	0.806***			0.893***		
	(0.170)			(0.159)		
F-first stage	31.2			20.28		
Open		-0.189***	-0.582***		0.006	0.012
		(0.064)	(0.136)		(0.020)	(0.033)
R-squared		0.522			0.278	
Sample size	103	103	103	103	103	103

C. Kyushu	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Open	Delay in completion	Delay in completion	Open	Log of quality score	Log of quality score
Estimator	First-stage OLS	OLS	IV	First-stage OLS	OLS	IV
Year	0.429***			0.423***		
	(0.103)			(0.102)		
F-first stage	4.1			4.06		
Open		0.048	-1.399**		0.014	0.025
		(0.101)	(0.626)		(0.017)	(0.063)
R-squared		0.300			0.262	
Sample size	82	82	82	82	82	82

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are presented in the right of the coefficients. All regressions include a constant term, the auction-level characteristics, the variables of geological conditions, meteorological conditions, economic environments and monthly dummy variables. The log of the reserve price is excluded for estimations on the relative winning bid (final payment). The log of the contractual time is excluded for estimations on the delay in completion.

Table 9: Estimation Results for the Procurement Costs through the DID

Dependent variable	Relative winning bid	Relative final payment	Cost overrun
Estimator	DID	DID	DID
Open	-0.020	-0.117**	-0.097*
	(0.015)	(0.055)	(0.055)
R-squared	0.252	0.225	0.210
Sample size	318	318	318

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are presented in the right of the coefficients. All regressions include a constant term, the variables of geological conditions, meteorological conditions, economic environments and monthly dummy variables. The log of the reserve price is excluded for estimations on the relative winning bid (final payment). The log of the contractual time is excluded for estimations on the delay in completion.

Table 10: Estimation Results for the Quality of Construction Works through the DID

Dependent variable	Delay in completion	Log of quality score
Estimator	DID	DID
Open	-0.262***	-0.003
	(0.058)	(0.013)
R-squared	0.556	0.091
Sample size	318	318

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are presented in the right of the coefficients. All regressions include a constant term, the variables of geological conditions, meteorological conditions, economic environments and monthly dummy variables. The log of the reserve price is excluded for estimations on the relative winning bid (final payment). The log of the contractual time is excluded for estimations on the delay in completion.

Table 11: Summary Statistics for New Participants

Kanto	Invited	New Participants in Open Auctions
Variable	Mean Standard deviation	Mean Standard deviation
Relative winning bid	0.87	0.87
	(0.10)	(0.07)
Relative final payment	1.07	1.06
	(0.27)	(0.29)
Cost overrun	0.23	0.22
	(0.27)	(0.29)
Quality score of work	74.70	75.35
	(5.13)	(3.75)
Delay in completion	0.68	0.33
	(2.69)	(0.47)
Sample size	300	74

Shikoku	Invited	New Participants in Open Auctions
Variable	Mean Standard deviation	Mean Standard deviation
Relative winning bid	0.94	0.90
	(0.04)	(0.07)
Relative final payment	1.17	1.09
	(0.22)	(0.19)
Cost overrun	0.24	0.21
	(0.21)	(0.18)
Quality score of work	74.84	75.11
	(3.95)	(4.20)
Delay in completion	0.32	0.10
	(0.36)	(0.21)
Sample size	38	36

Kyushu	Invited	New Participants in Open Auctions
Variable	Mean Standard deviation	Mean Standard deviation
Relative winning bid	0.87	0.87
	(0.08)	(0.08)
Relative final payment	1.28	1.06
	(0.45)	(0.30)
Cost overrun	0.46	0.22
	(0.44)	(0.29)
Quality score of work	74.17	75.30
	(2.83)	(3.30)
Delay in completion	0.11	0.43
	(0.24)	(0.57)
Sample size	41	56

Note: Robust standard deviations are in parentheses.

Table 12: Results for New Participants on the Procurement Costs

A. Kanto	(1)	(2)	(3)
Dependent variable	Relative winning bid	Relative final payment	Cost overrun
Estimator	OLS	OLS	OLS
New participants	0.010	0.008	-0.006
	(0.009)	(0.037)	(0.037)
R-squared	0.233	0.165	0.160
Sample size	587	587	587

B. Shikoku	(1)	(2)	(3)
Dependent variable	Relative winning bid	Relative final payment	Cost overrun
Estimator	OLS	OLS	OLS
New participants	-0.035*	-0.050	0.002
	(0.019)	(0.049)	(0.058)
R-squared	0.335	0.197	0.147
Sample size	137	137	137

C. Kyushu	(1)	(2)	(3)	(4)
Dependent variable	Relative winning bid	Relative final payment	Log of extra cost	Log of final payment
Estimator	OLS	OLS	OLS	OLS
New participants	-0.009	-0.075	-0.079	-0.076*
	(0.014)	(0.053)	(0.058)	(0.045)
R-squared	0.234	0.290	0.247	0.568
Sample size	192	192	192	192

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are presented in the right of the coefficients. All estimation models include a constant term, the auction-level characteristics, the variables of geological conditions, meteorological conditions, economic environments and monthly dummy variables. The log of the reserve price is excluded for estimations on the relative winning bid (final payment). The log of the contractual time is excluded for estimations on the delay in completion.

Table 13: Results for New Participants on the Quality of Construction Works

A. Kanto	(1)	(2)
Dependent variable	Delay in completion	Log of quality score
Estimator	OLS	OLS
New participants	-0.175*	0.012
	0.093	0.007
R-squared	0.031	0.081
Sample size	587	587

B. Shikoku	(1)	(2)
Dependent variable	Delay in completion	Log of quality score
Estimator	OLS	OLS
New participants	0.003	0.012
	0.060	0.015
R-squared	0.291	0.187
Sample size	137	137

C. Kyushu	(1)	(2)
Dependent variable	Delay in completion	Log of quality score
Estimator	OLS	OLS
New participants	0.229***	0.005
	0.081	0.007
R-squared	0.267	0.212
Sample size	192	192

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are presented in the right of the coefficients. All estimation models include a constant term, the auction-level characteristics, the variables of geological conditions, meteorological conditions, economic environments and monthly dummy variables. The log of the reserve price is excluded for estimations on the relative winning bid (final payment). The log of the contractual time is excluded for estimations on the delay in completion.

Table A1: Summary Statistics of the Independent Variables

Kanto	Invited	Open
Variable	Mean (Standard deviation)	Mean (Standard deviation)
Reserve price	1.49E+08	1.49E+08
	(2.97E+07)	(2.93E+07)
Contractual length	230.18	229.08
	(91.21)	(80.13)
Number of potential bidders	7.99	6.45
	(3.91)	(5.74)
Material price	114.51	118.66
	(3.96)	(4.33)
Income	3225464	3506487
	(516756)	(836319)
Precipitation	1517.67	1324.49
	(252.55)	(230.41)
Minimum temperature	3.84	3.34
	(2.81)	(2.78)
Surface ground	344.34	319.43
	(173.03)	(152.09)
Fault	0.01	0.01
	(0.07)	(0.06)
Landslide	0.06	0.05
	(0.20)	(0.16)
Liquefaction	3.17	3.05
	(0.79)	(0.73)
Road	0.51	0.56
	(0.50)	(0.50)
River	0.35	0.28
	(0.48)	(0.45)
Bridge	0.14	0.16
	(0.34)	(0.37)
Sample size	300	287

Shikoku	Invited	Open
Variable	Mean (Standard deviation)	Mean (Standard deviation)
Reserve price	1.48E+08	1.52E+08
	(2.98E+07)	(3.85E+07)
Contractual length	247.34	253.22
	(55.42)	(49.42)
Number of potential bidders	10.84	9.86
	(2.89)	(3.77)
Material price	112.14	118.49
	(7.80)	(4.84)
Income	2793803	2865816
	(237092.8)	(261010.1)
Precipitation	1745.32	1884.99
	(374.32)	(702.96)
Minimum temperature	4.67	6.39
	(1.77)	(1.85)
Surface ground	579.26	429.93
	(174.53)	(163.61)
Fault	0.13	0.18
	(0.22)	(0.26)
Landslide	0.11	0.03
	(0.30)	(0.13)
Liquefaction	3.51	3.09
	(0.59)	(0.59)
Road	0.42	0.60
	(0.50)	(0.49)
River	0.37	0.29
	(0.49)	(0.46)
Bridge	0.21	0.11
	(0.41)	(0.32)
Sample size	38	99

Kyushu	Invited	Open
Variable	Mean (Standard deviation)	Mean (Standard deviation)
Reserve price	1.35E+08	1.44E+08
	(2.70E+07)	(2.90E+07)
Contractual length	298.07	225.06
	(86.62)	(52.56)
Number of potential bidders	12.76	13.77
	(5.02)	(6.08)
Material price	103.46	108.57
	(0.81)	(5.13)
Income	2801063	2697619
	(325195.4)	(285095.2)
Precipitation	2305.33	2181.39
	(448.74)	(559.19)
Minimum temperature	7.05	6.25
	(1.73)	(1.63)
Surface ground	415.86	404.24
	(133.71)	(160.16)
Fault	0.07	0.08
	(0.13)	(0.19)
Landslide	0.06	0.07
	(0.16)	(0.21)
Liquefaction	3.30	3.18
	(0.51)	(0.63)
Road	0.83	0.50
	(0.38)	(0.50)
River	0.12	0.34
	(0.33)	(0.47)
Bridge	0.05	0.16
	(0.22)	(0.37)
Sample size	41	151

Note: Based on the classification of 7 project types, we create three project-type dummies: road, river and bridge dummies. The road dummy consists of asphalt paving work, road construction works and road maintenance and rehabilitation. The river dummy is composed of river works in general civil engineering work and maintenance and rehabilitation work. The bridge dummy consists of bridge construction works and bridge maintenance and rehabilitation. Standard Deviations are in parentheses.

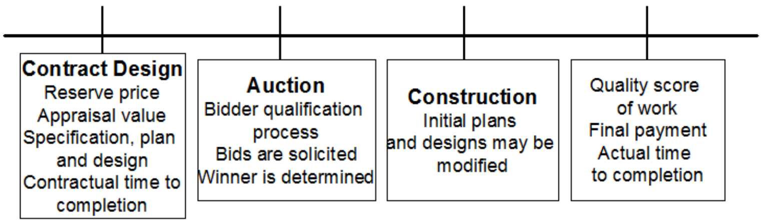


Figure 1: The Procurement Process of Public-work Contracts

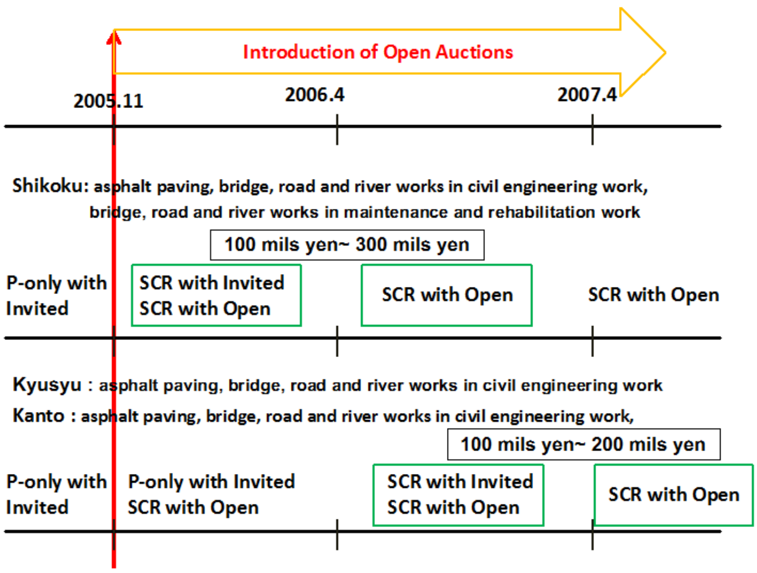


Figure 2: The Flow of Policy Changes in Public Procurement Auctions Held by the MLIT

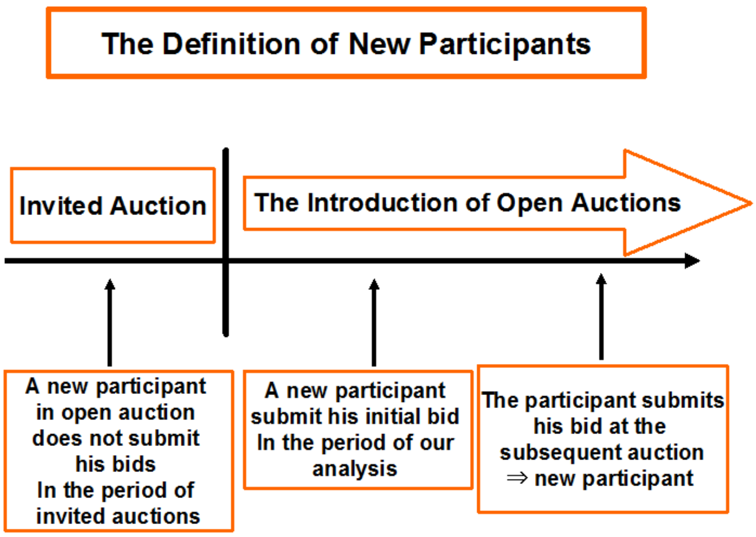
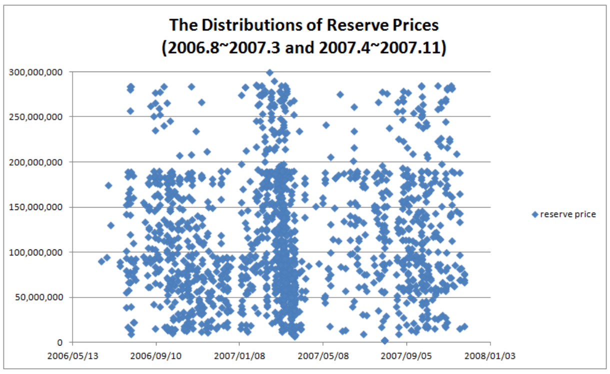
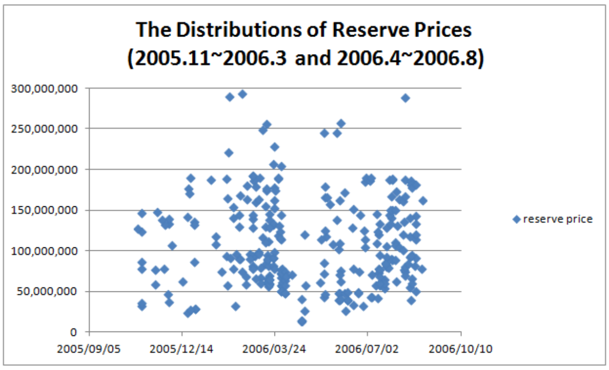


Figure 3: The Definition of New Participants



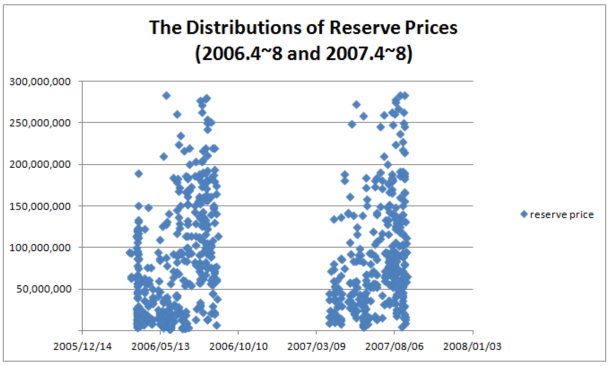
Kanto	2006.8-2007.3		2007.4-2007.11	
Size of a contract	Number of contracts	Percentage of contracts	Number of contracts	Percentage of contracts
-50 (JPY; mils)	178	0.16	58	0.12
50-100 (JPY; mils)	354	0.32	143	0.29
100-200 (JPY; mils)	413	0.38	212	0.42
200-300 (JPY; mils)	100	0.09	66	0.13
300 (JPY; mils)-	54	0.05	20	0.04
Total	1099	1.00	499	1.00

Figure 4: The Distribution of Contract Sizes in Kanto



Shikoku	2005.11-2006.3		2006.4-2006.8	
Size of a contract	Number of contracts	Percentage of contracts	Number of contracts	Percentage of contracts
-50 (JPY; mils)	9	0.06	20	0.13
50-100 (JPY; mils)	58	0.40	61	0.39
100-200 (JPY; mils)	64	0.44	66	0.43
200-300 (JPY; mils)	8	0.06	3	0.02
300 (JPY; mils)-	6	0.04	5	0.03
Total	145	1.00	155	1.00

Figure 5: The Distribution of Contract Sizes in Shikoku



Kyushu	2006.4-2006.8		2007.4-2007.8	
Size of a contract	Number of contracts	Percentage of contracts	Number of contracts	Percentage of contracts
-50 (JPY; mils)	213	0.46	120	0.33
50-100 (JPY; mils)	101	0.22	123	0.34
100-200 (JPY; mils)	120	0.26	83	0.23
200-300 (JPY; mils)	28	0.06	26	0.07
300 (JPY; mils)-	5	0.01	9	0.02
Total	467	1.00	361	1.00

Figure 6: The Distribution of Contract Sizes in Kyushu

Chapter 4. Contractual Incompleteness and the Quality of Construction Works in Public-works Procurement: Empirical Analysis

1 Introduction

The share of public sector procurement ranges from 13 % to 20 % of GDP on average worldwide.[1] In public procurement, contracts are awarded through first price sealed bid auctions. However, in public-works procurement, the final payments determined at the time of completion are frequently higher than the winning bids because the contractors are faced with unanticipated productivity shocks during construction. The presence of cost overruns in the procurement auctions is reported not only in Japan but also in the United States, Italy, Spain and Brazil.[2] Public procurement should be effectively operated because some developed countries including Japan and the U.S are faced with huge government deficits. However, there is still a scarcity of the structural model of bidding which incorporates the presence of the cost overrun and the situation during construction into the model.

In this paper, we develop a structural model of a first-price sealed bid auction (a price-only auction) where the selected bidder chooses the quality level and the cost overrun is considered as an incentive scheme to ensure the quality of work. In this model, a contract is awarded through a first price sealed-bid auction, but a cost overrun arises and the contractor determines the quality level during construction due to the presence of unanticipated shocks. Similar to Weitzman (1980) and McAfee and McMillan (1986), the contract presented by the government makes a payment to the contractor a linear function of its bid and its cost overrun, where the cost overrun is linear in the quality level. After a contractor is selected through an auction, the contractor who has the cost function of the quality level determines the quality of work during construction. Considering the linear contract and the ex post stage, bidders develop their bidding strategies at the auction stage. In the equilibrium, the quality of work is increasing with the cost overrun. This situation is close to the moral hazard because the cost overrun improves the contractor's effort level for the quality of work. Hence, the situation like the moral hazard problem is incorporated into the auction model.

For our empirical analysis, we use a unique data set of first-price sealed bid auctions in public-works procurement in Japan. The data set includes the quality score of work reviewed after the completion and the final payment in addition to the bids and the number of bidders in each contract. The

[1] See http://www.oecd.org/gov/ethics/oecdjointlearningstudies.htm

[2] For the information, see Bajari, Houghton and Tadelis (2014), Decarolis (2014), Ganuza (2007) and Fiuza and Rezende (2012).

quality score includes information on the performance of work such as verticality and horizontality in foundation construction in addition to information on the completion time.

We identify and estimate the structural auction model by using the data set. We need multi-dimensional information because we consider not only the cost of a contract but also a cost function of the quality level. The structural model consists of both the equilibrium relation between the winning bid and the winning bidder's cost, and the relation between the cost overrun and the quality of work because our model is a two stage game, in which bidders develop their bidding strategies at the auction stage and the winning bidder determines the quality of work during construction. Moreover, from the data set, we have information on the quality of work and the cost overrun at the ex post stage, and the winning bid and the number of bidders at the auction stage. Hence, this structural model and the data set enable us to recover the winning bidder's cost and the cost function of the quality level.

The estimation results show that the functional form of the cost is smooth. The fixed cost accounts for 84% of the estimated cost on average. The functional forms of the costs are different between the sizes of contracts. For the smallest-scale contracts, the fixed cost accounts for 67% of the estimated cost on average, while for the largest-scale contracts, the fixed cost amounts to 94% of the estimated cost on average.

In counterfactual experiments, we simulate the quality of work and social welfare when the cost overruns are reduced. When the cost overruns are reduced by 25% (50%), the welfare loss for the government is nearly 13% (40%). The net value of the welfare loss is JPY 3.5 million or approximately USD 35 thousand (JPY 13 million or approximately USD 130 thousand) per contract when the cost overrun is discounted by 25% (50%). When the cost overruns are abolished, the quality score of work is almost 0 and social welfare takes negative values.

This is the first paper which provides empirically tractable structural auction model considering not only bidding strategies at the auction stage but also the choice of the quality level during construction. Bajari and Tadelis (2001) show that cost-plus contracts like negotiations work well to procure complex projects because the ex-post adaptations frequently arise for the projects. McAfee and McMillan (1986) develop a model which incorporates the moral hazard problem into a first price sealed bid auction. Ganuza (2007) and Wang (2000) theoretically examine how renegotiation arises in public procurement auctions. Bajari, Houghton and Tadelis (2014) and Miller (2014) measure the adaptation costs generated by the ex-post adaptations by estimating a structural auction model. Lewis and Bajari (2014) empirically investigate the moral hazard problem due to unanticipated productivity shocks in the procurement of road constructions. However, the empirical studies do not incorporate the choice of the quality of work during construction into the auction model. In this paper, we develop a empirically tractable structural auction model with the cost overruns and the endogenous choices of quality levels. This model enables us to evaluate the impacts of the cost overruns on the quality of work and the welfare gain. The empirical auction literature considering the presence of the cost overruns remain scarce in spite of the prevalence of cost overruns in public-works procurement. Therefore, this paper contributes to the empirical and theoretical auction literature which considers not only bidding strategies at the auction stage but also the stage during construction.

This paper is also related to the structural estimation approach to analyze public procurement auctions (Brannman and Froeb (2000), Hong and Shum (2002), Bajari and Ye (2003), Jofre-Bonet and Pessendorfer (2003), Li and Ji (2006), Flambard and Perrigne (2006), Marion (2007), Li and Zheng (2009), Nakabayashi (2009), Krasnokutskaya (2011), Krasnokutskaya and Seim (2012), Somaini (2012), Balat (2012), Decarolis (2013), Bhattacharya, Roberts and Sweeting (2014), Groeger (2014)).

The paper is organized as follows. Section 2 presents the auction data, summary statistics and some preliminary analyses. Section 3, 4 and 5 provide a first price sealed bid auction model, counterfactual scenarios and the identification of the model. Section 6 shows the estimation methods. Section 7 is devoted to present estimation results and the counterfactual simulations. Section 8 concludes this paper.

2 The System of Procurement, Data and Preliminary Analysis

2.1 Procurement System

This section provides public-works procurement system under the Ministry of Land Infrastructure and Transportation (the MLIT) in Japan. The MLIT operates nationwide public-works procurement. It is in charge of eight regional bureaus (Tohoku, Hokuriku, Kanto, Chubu, Kinki, Chugoku, Shikoku and Kyushu) and Hokkaido regional development bureau. Each regional bureau is the local agency of the MLIT and has its own territory. The regional bureaus are in charge of the procurement of contracts in their territories.

The public procurement takes place as illustrated in Figure 1. In the phase of designing a contract, officials in the government present the specification, the plan, the reserve price, the appraisal value and the length of the contract in days (the engineer's days estimate). The reserve price is constructed based on the initial specification and plan presented by the government. The appraisal value is a minimum price to avoid too aggressive bidding. It is constructed as about 70% of the value of a reserve price

In the phase of bidding, the government uses two bidder qualification processes, namely, invited and open auctions. In an invited auction, only selected firms by the government are given contract information and are allowed to place bids. In the auction, the government chooses about 10 firms which satisfies certain conditions including financial conditions prior to auction. In an open auction, the government advertises a contract broadly and publicly and any firms who satisfy minimum requirements including financial conditions can voluntarily submit bids. Open auctions tend to be used to award large-scale contracts in the period for our analysis.

Contracts are awarded through a small business set-aside program in the market for our analysis. Under the program, only small firms are allowed to submit bids in auctions for small-scale contracts, while large firms are excluded from the auctions. A rating system determines the contract size in which a firm is allowed to bid. The rating system considers the firm's financial condition, the number of engineers employed and the firm's construction revenue. When a firm is qualified as a large (small) business through the rating system, the firm is allowed to submit bid in an auction for a large (small)-scale contract. The government updates this information every one or two years. Table 1 shows that firms with rank A or B (C or D), which are qualified as large (small) firms, are basically allowed to submit bids in the auctions for rank A or B (C or D) in which large (small)-scale contracts are awarded.[3] Table 1 indicates that in auctions for rank C and D, about 95% of firms participating in auctions are qualified as rank C and D. In auctions for rank A and B, about 90% of firms participating in auctions are qualified as rank A and B.

After qualifying bidders, a first-price sealed-bid auction (a price-only auction) with a secret reserve price is used to award a contract. In this auction, bidders submit prices. If the lowest price is lower than the reserve price, the contract is awarded to the bidder with the lowest price. The reserve price is kept secret at the time of bidding. After bids are opened, the reserve price is publicly announced.

Considerable differences between the winning bids and the final payments frequently arise due to unpredictable shocks during project construction. During construction, the contractor is faced with a lot of problems from geological and meteorological conditions at the project location. The initial specifications and payments at the time of bidding are sometimes insufficient to ensure the appropriate quality standards due to the presence of the shocks. As a result, cost overruns occur in order to ensure the quality of construction works appropriately. According to people in the construction industry, they rationally anticipate the modifications of initial specifications and plans at the time of bidding based

[3]In rank A, contracts with a reserve price above JPY 730 million are awarded, in rank B, contracts with a reserve price between JPY 300 and 730 million are awarded, in rank C, contracts between JPY 60 and 300 million are awarded and in rank D, contracts below 60 million yen are awarded.

on their past experiences.

Engineers in the government assign the quality score of work in each contract by reviewing the quality of work during construction and after the completion.[4] The quality score is composed of the performance of work, the quality of work, the level of completed work, the level of execution management, the system of the execution of work, the safety management, the schedule control (up to these factors, more than 70 % of the score is constituted), the consideration to the environment around the project site, the ingenuity for the execution of work, the ability of engineers, the technology level used to perform work and the legal compliance. The quality score has a range between 0 to 100 points and the base value of the score is set as 65. The same evaluation criteria are implemented for all the work projects procured by the MLIT.

2.2 Data and Summary Statistics

We exploit the data of public-works procurement operated by the eight regional bureaus from April 2005 to March 2007. In the period, the eight regional bureaus under the MLIT awarded 23396 contracts in total. The 23396 contracts contains electric insulation work, machinery equipment, upper structure of bridge and road painting in addition to the construction of roads. We choose price-only auctions in the period. In particular, for our empirical analysis, we concentrate on the procurement of road work projects including the construction and maintenance of roads, public utility conduits, box culverts and tunnels and paving work projects because the work projects are affected by unpredictable productivity shocks during construction.

For each contract, our data set provides information on the reserve price, the appraisal value, the project location, the contractual time to complete the work, the actual time to complete the work, the individual bids and their identities, the winning bid, the final payment, the identity of firms invited by the government in an invited auction, the identity of firms which show their interests for a project in an open auction and the quality score of work.

In this paper, firms which are allowed to bid for a contract are treated as potential bidders in an invited auction, while firms which show their interests for a certain project and satisfy the minimum restrictions are treated as potential bidders in an open auction. In both of the auctions actual bidders are defined as firms which eventually place bids. The potential bidders do not necessarily submit bids

[4]Someone may be concerned with the reliability of the quality score because the score is possibly affected by discretion and power exercised by officials in the government for their private gain including corruption. However, the reliability of the quality score in our analysis is ensured because the ranking of Japan is 21th and that of the United States is 17th in the ranking for corruption perceptions index (CPI) reported by Transparency International in 2005. The CPI score was 7.3 for Japan and 7.6 for the United States. Corruption levels in the public sector measured by Kaufmann, Kraay and Mastruzzi (2005), which are used in Fishman and Miguel (2007), also indicate the same tendency as the CPI score. These indices allow us to consider that the quality score is reliable.

because some bidders find more profitable contracts. It leads to the difference between the number of potential bidders and the number of actual bidders.

Table 2 shows a summary statistics of the procurement data. The data set provides 1350 auctions. In the data set, the invited auctions are dominant. Table 1 shows that the average difference between the winning bid and the final payment is positive with the value of 24%. In about 88% of contracts, cost overruns arise. Hence, the presence of cost overruns is important for the procurement of road work projects. We are interested in the relation between the number of potential bidders and the number of actual bidders. The number of potential bidders is very close to the number of actual bidders because the number of potential bidders is 9.9 on average and the number of actual bidders is 9.1 on average. We find that more than 90% of potential bidders eventually submit bids. We observe that the quality scores vary across auctions because the variance of the quality score is not small. In addition, the quality score of work is 72 on average and more than the base value of the score (65).

We investigate whether bidders are symmetric or not. In the market, the top share contractors win less than 3% in the entire period of analysis. More than 95% of contractors win less than 1% of contracts. Hence, there are only fringe bidders in the market. In addition, the MLIT implements the policy of small business set aside to all the auctions for our analysis. Hence, small (large) bidders compete with small (large) ones in auctions for small-scale contracts. As a result, in the market for our analysis, we find that bidders are basically symmetric.

2.3 The definition of Variables

There are four auction-level characteristics: the log of the reserve price, the log of the contract length and the number of potential bidders (the log of the number of potential bidders). The log of the reserve price and the log of the contract length control for the differences in the size of a contract across auctions. The number of potential bidders controls for the difference in competition across auctions.

We provide four variables to control for geological conditions that change across contracts because road work projects are generally affected by geological conditions at the project location. We also use the following two variables for difference in meteorological conditions across the project location: the precipitation and minimum temperature. Meteorological factors influence geological conditions at the project location through the condition of groundwater. We exploit two variables to control for the difference in the business environment around the project location: the construction materials prices and the income level around the project location. We describe the definitions of these variables in the Appendix.

2.4 Reduced-Form Analyses

We examine the public procurement auction for road work projects. First, we examine whether the cost overrun depends on the quality score of work because we assume that the form of the final payment consists of its bid and its cost overrun which is linear in the quality of work as described before. Second, we check whether the auctions are competitive or not.

We investigate the relation between the quality score of work and the cost overrun to check whether the extra payment improve the quality of work. For the analysis, we estimate the following regression model at auction a:

$$Y_a = \beta_1 + \beta_2 E_a + X_a'\beta_3 + \epsilon_a$$

Y_a is the log of a cost overrun and E_a is the quality score of work. X_a' includes the auction-level variables, variables representing the economic environment, variables measuring geological and meteorological conditions and monthly dummies. Our main interest is the sign of β_2 and whether β_2 is statistically significant or not. Table 3 shows that β_2 is significantly positive. This result suggests that the cost overrun is used to ensure the quality of work.

We use an instrumental variable to cope with the measurement error problem for the quality score of work. For the instrumental variable, we propose the variable of completion time which is constructed as the difference (in days) between the actual time to complete the work and the contractual time to complete the work divided by the contractual time to complete the work. We consider that the completion time is valid as the instrumental variable because it is one of the quality measures in public-work projects.[5] The estimation result is shown in Table 3. The estimation result also suggests that the cost overrun is positively correlated with the quality score of work. Based on the estimation results, we consider that the cost overrun ensures the quality of work.

Second, we empirically examine whether auctions are competitive or not. We estimate the following regression model at auction a:

$$Y_a = \beta_1 + \beta_2 N_a + X_a'\beta_3 + \epsilon_a$$

The dependent variable Y_a is the log of the winning bid or the relative winning bid. N_a is the number of potential bidders or the log of the number of potential bidders. The other explanatory variables are the same as the above specification. Our main interest is whether β_2 is significantly negative or not

[5] Lewis and Bajari (2011) and Decarolis (2014) also use the completion time as the measure of the quality of work when analyzing public procurement auctions.

because β_2 infers the effect of competition in auctions. As Table 4 shows, β_2 is basically significantly negative for the regressions of the winning bid when we use the number of potential bidders. However, β_2 is not significantly negative when we exploit the log the number of potential bidders.

We consider the other econometric model where the number of potential bidders is represented by a vector of dummy variables. The estimation model at auction a is provided by

$$Y_a = \beta_1 + \beta_2 D_a^{'}(N_a) + X_a'\beta_3 + \epsilon_a$$

where $D_a^{'}(N_a) = 1\{N_a = n\}$ is the vector of dummy variables which represent the number of potential bidders N_a at auction a. The other explanatory variables are the same as the previous models. This regression model is also used in Shneyrov (2006) and Tang (2011). Table 5 shows that the number of potential bidders has significantly negative effects on the bidding behavior. Hence, from the estimation results, we consider that the auctions are competitive.

3 Theoretical Model

3.1 Equilibrium Bidding Behavior in a First-price Sealed Bid Auction

In this section, we construct an auction model with the presence of a cost overrun. Similar to Weitzman (1980) and McAfee and McMillan (1986), we assume that the government specifies the form of a linear payment schedule which is contingent on both the winning bidder's bid and the cost overrun. We also assume that the cost overrun is an incentive scheme to induce the contractor's effort for improving the quality of work during construction. In this model, each bidder takes the presence of the cost overrun and the choice of the quality of work into account at the time of developing their bidding strategies. After bidding, the selected bidder chooses the quality of work during construction.

There are N risk neutral symmetric bidders. Prior to bidding, each bidder receives private information θ which corresponds with its cost parameter. Each bidder submit a sealed bid b. We denote the winning bid by w. Bidders' private information (θ) is drawn from a independently and identical distribution $F_\theta(\cdot)$ with the density $f_\theta(\cdot)$ over $[\underline{\theta}, \bar{\theta}]$. The cost function $C(Q, \theta)$ is assumed to be strictly increasing in θ. We assume that the cost function is $C_Q > 0$ and $C_\theta > 0$. The reserve price is denoted as r which is drawn from a distribution $H(\cdot)$ with the density $h(\cdot)$. The reserve price is independent of bidder' private information θ. $F_\theta(\cdot)$, $C(Q, \theta)$, N and $H(\cdot)$ are assumed to be common knowledge among bidders.

The expected profit function for each firm is described as follows:

$$\Pi(b, Q) = [b + E(P) - C(Q, \theta)]\text{Prob}(\text{win}|b)$$

In this model, each firm faces the uncertainty of the cost overrun P at the time of bidding due to the presence of unpredictable shocks during construction. The variable (P) represents the difference between the winning bid and the final payment. As described before, this specification corresponds with the real world public-works procurement. This formulation is analogous to Bajari, Houghton and Tadelis (2014) in that the cost overrun is incorporated in the expected profit function.

Moreover, we assume:

$$E(P) = E(\gamma)Q$$

where γ is a random variable representing the cost overrun per the quality of work. The cost overrun P depends on the quality level offered by the contractor Q because the cost overrun arises in order to ensure the quality of work. The expected value of γ, $E(\gamma)$, is assumed to be common. This specification means that bidders do not have exact information on the value of γ at the time of bidding. Hence, the expected profit function for each bidder is rewritten as:

$$\begin{aligned}\Pi(b, Q; \theta) &= [b + E(\gamma)Q - C(Q, \theta)]\text{Prob}(\text{win}|b)\\ &= [b + E(\gamma)Q - \theta Q^2 - \alpha]\text{Prob}(\text{win}|b)\end{aligned}$$

where the cost function is assumed as follows: $C(Q, \theta) = \theta Q^2 + \alpha$ where $\theta > 0$ and $\alpha > 0$.

We consider the optimization problem for each bidder. The method of solving the optimization problem is similar to Che (1993) and Asker and Cantillon (2008).[6] First, fixing price b, each bidder chooses a quality level. After that, putting the quality level into the expected profit function, we obtain the optimization problem to determine the equilibrium price. This means that in equilibrium, the quality level is separately determined from the price. Hence, in equilibrium, the quality level is determined as follows:

$$\max_Q E(\gamma)Q - \theta Q^2 - \alpha \Leftrightarrow Q^*(\theta) = \frac{E(\gamma)}{2\theta}$$

Substituting $Q^*(\theta)$ into the expected profit function, the optimization problem of choosing b is

[6] Bajari, Houghton and Tadelis (2014) also adopt their approaches.

written as:

$$\max_b \Pi(b, Q^*(\theta); \theta) \Leftrightarrow \max_b \left[b - \alpha + \frac{E(\gamma)^2}{4\theta} \right] \text{Prob}(\text{win}|b)$$

We then call $c = \tilde{C}(Q^*(\theta), \theta) = \tilde{c}(\theta) = \alpha - \frac{E(\gamma)^2}{4\theta}$ as a pseudo cost in the expected profit function. We assume that bidders develop their bidding strategies based on the pseudo type c. The pseudo type c is assumed to follow a distribution $F(\cdot)$. Assuming that $\sigma(\cdot)$ is a strategy representing the following strictly increasing function: $c \rightarrow b$, we derive the equilibrium bidding strategy in the same method as Elyakime, Laffont, Loisel and Vuong (1994) and Li and Perrigne (2003). The winning probability is given by:

$$\text{Prob}(\text{win}|b) = (1 - F(\sigma^{-1}(b)))^{N-1}(1 - H(b))$$

The bidders' optimization problem of choosing b is rewritten as:

$$\max_b \, [b - c](1 - F(\sigma^{-1}(b)))^{N-1}(1 - H(b))$$

This is the same as the model of a first price sealed bid auction with a secret reserve price considered in Elyakime et al. (1994) and Li and Perrigne (2003). Hence, the unique symmetric equilibrium price solves the following equation:

$$\sigma^{'}(c)(1 - F(c))(1 - H(\sigma(c))) = (\sigma(c) - c)[(N - 1)f(c)(1 - H(\sigma(c))) + (1 - F(c))h(\sigma(c))\sigma^{'}(c)] \quad (1)$$

where $c = \alpha - \frac{E(\gamma)^2}{4\theta}$. The equilibrium strategy $\sigma(\cdot)$ solves the differential equation subject to the boundary condition $\underline{c} = \sigma(\underline{c})$.

We consider the optimization problem for the government. Let the government be risk-neutral. The government has a private value v_B of a contract that is drawn from a distribution $F_B(\cdot)$. The distribution function is independent of $F_\theta(\cdot)$. We assume that the government also faces the uncertainty of the cost overrun in the course of designing the contract. Under a first price auction with a secret reserve price, the government sets the reserve price r to minimize her expected cost: $E[(v_B - E(P) - W)1(W \leq r)]$ where $W = \sigma(c_{1:N})$ where $W = \sigma(c_{1:N})$. As Elyakime et al. (1994) show, the government's optimal strategy is truth telling and $v_B - E(P) = r$.

4 Counterfactual Scenarios

We consider the quality level and social welfare in the first price auction model in which the cost overrun arises and the contractor chooses the quality of work when an cost overrun is reduced. Let k denote the discount rate of the cost overrun. When the cost overrun is discounted, the quality of work is given by

$$\max_Q kE(\gamma)Q - \theta Q^2 - \alpha \Leftrightarrow Q^{**}(\theta) = \frac{kE(\gamma)}{2\theta}$$

where $0 < k < 1$. We then obtain social welfare at the quality level:

$$V(Q^{**}(\theta)) - C(Q^{**}(\theta), \theta) = V(Q^{**}(\theta)) - \alpha + \frac{k^2 E(\gamma)}{4\theta}$$

Comparing $Q^{**}(\theta)$ with $Q^{*}(\theta)$, we have:

$$\frac{kE(\gamma)}{2\theta} < \frac{E(\gamma)}{2\theta}$$

We find that the quality level under the cost overrun of $E(\gamma)$ is larger compared with the quality level under the cost overrun of $kE(\gamma)$. The quality level is 0 when the cost overrun is equal to 0 ($k = 0$). As mentioned before, the cost overrun is considered to be an incentive scheme to ensure the quality of work. The inequality means that the contractors deliver the quality of construction works observed in the data set because the cost overruns are sufficiently given.

This situation is similar to the moral hazard problem. The selected bidder chooses the quality level because of the presence of unanticipated shocks in the course of construction. When the cost overrun is not given, the contractor chooses the lowest quality level. Hence, we consider that the cost overrun gives the contractor an incentive to exert her effort to improve the quality of work.

5 Identification of the Structural Model

In this section, we identify the structural model. In the structural model, there are two FOCs and two unknown values: $(\alpha, F_\theta(\cdot))$. The data set contains information on the quality score of work (Q), the winning bid (w) and the extra payment (P) in each contract. The two FOCs are written as:

$$\alpha - \frac{E(\gamma)^2}{4\theta_{1:N}} = \xi(w) = w - \frac{(1 - G_W(w))(1 - H(w))}{\frac{N-1}{N} g_W(w)(1 - H(w)) + (1 - G_W(w))h(w)} \tag{2}$$

$$Q^*(\theta_{1:N}) = \frac{E(\gamma)}{2\theta_{1:N}} \tag{3}$$

where $G_W(w)$ is the distribution function of winning bids and $g_W(w)$ is the density function of winning bids. The first equation is derived by the characteristic of the order statistics and the change of variables as in Guerre, Perrigne and Vuong (2000).

We identify $(\alpha, \theta_{1:N})$ by solving the equations which consist of the two FOCs because we have information on Q, N, $E(\gamma)$ w, $H(w)$, $h(w)$, $G_W(w)$ and $g_W(w)$ from the data set. In addition to that, we obtain $F_{\theta_{1:N}}(\cdot) = F_\theta(\cdot)^{N-1}$ from the bidder symmetry, the independence of cost parameters and the characteristics of the order statistics. Hence, we identify $F_\theta(\cdot)$.

6 Estimation Methods

In this section, we provide the estimation methods of the cost parameter and the fixed cost $(\alpha, \theta_{1:N})$. The estimation method consists of three steps. Firstly, we estimate $E(\gamma)$ from the cost overrun and derive $\theta_{1:N}$ from one of the FOCs. Second, we nonparametrically estimate the winning bid distribution, the corresponding density functions, the reserve price distribution and its corresponding density function. We estimate the winning bidders' pseudo costs by using information on those functions and the number of bidders. Finally, α is derived from the winning bidder's pseudo estimated cost.

The characteristics for the auctioned contracts vary across auctions $t = 1, ..., T$. Let x_t be covariates characterizing the auctioned contracts which change across T auctions. The covariates x_t control for heterogeneity across auctioned contracts. In addition, let N_t be the number of bidders in each auction. Hence, we provide the distribution and density functions described above as conditional distribution and density functions: $G_W(\cdot|x_t)$, $g_W(\cdot|x_t)$, $H(\cdot|x_t)$ and $h(\cdot|x_t)$. In this paper, we use the appraisal value as the covariate. The approach of single covariate is used in Elyakime et al. (1994), Li and Perrigne (2003) and Marion (2007). Thus, we obtain

$$\alpha - \frac{QE(\gamma|x)}{2} = \xi(w) = w - \frac{(1 - \hat{G}_W(w|x))(1 - \hat{H}(w|x))}{\frac{N-1}{N} \hat{g}_W(w|x)(1 - \hat{H}(w|x)) + (1 - \hat{G}_W(w|x))\hat{h}(w|x)}$$

where

$$
\begin{aligned}
&E(P|x) = \beta x \\
&\hat{G}_W(w|x) = \frac{\hat{G}(w,x)}{m(x)} = \frac{\frac{1}{Th_W}\sum_{t=1}^{T} 1\mathbb{I}(W_t \le w) k(\frac{x-x_t}{h_W})}{\frac{1}{Th_x}\sum_{t=1}^{T} k(\frac{x-x_t}{h_x})} \\
&\hat{H}(w|x) = \frac{\hat{H}(w,x)}{m(x)} = \frac{\frac{1}{Th_R}\sum_{t=1}^{T} 1\mathbb{I}(R_t \le w) k(\frac{x-x_t}{h_R})}{\frac{1}{Th_x}\sum_{t=1}^{T} k(\frac{x-x_t}{h_x})} \\
&\hat{g}_W(w|x) = \frac{\hat{g}(w,x)}{m(x)} = \frac{\frac{1}{Th_w{}^2}\sum_{t=1}^{T} k(\frac{w-W_t}{h_w}) k(\frac{x-x_t}{h_w})}{\frac{1}{Th_x}\sum_{t=1}^{T} k(\frac{x-x_t}{h_x})} \\
&\hat{h}(w|x) = \frac{\hat{h}(w,x)}{m(x)} = \frac{\frac{1}{Th_r{}^2}\sum_{t=1}^{T} k(\frac{w-R_t}{h_r}) k(\frac{x-x_t}{h_r})}{\frac{1}{Th_x}\sum_{t=1}^{T} k(\frac{x-x_t}{h_x})}
\end{aligned}
$$

where h_W, h_w, h_R, h_r and h_x are bandwidths and $k(\cdot)$ is a kernel function. We obtain $E(\gamma|x)$ by calculating $E(P|x)/Q$ for each contract.

To reduce the skewness of bid data, we implement the estimation method used by Li and Perrigne (2003) and Marion (2007). Thus, we consider the log transformation of the winning bids. In this case, the transformed FOC is given by:

$$
\alpha + \frac{QE(\gamma)}{2} = exp(wd) - \frac{exp(wd)}{\frac{N-1}{N}\frac{g_{wd}(wd)}{1-G_{wd}(wd)} + \frac{h_{Rd}(wd)}{1-H_{Rd}(wd)}} \qquad \text{and} \qquad \hat{\theta}_{1:N} = \frac{E(\gamma)}{2Q}
$$

where $wd \equiv \log w$ and $Rd \equiv \log r$. G_{Wd} and g_{Wd} are the distribution function and its corresponding density functions for the log transformed bids. From the two equations, we obtain $\hat{\theta}_{1:N}$ and $\hat{\alpha}$. The estimation procedure to obtain those functions is the same as the above.

A problem for using kernel estimators is biases near the boundaries of the support. To correct bias, we perform a trimming which is developed by Guerre et el. (2000).

We consider the choice of kernel functions and bandwidths. The triweight kernel function is commonly used in nonparametric estimations in empirical auction papers. The form of triweight kernel function is $K(u) = \frac{35}{32}(1-u^2)^3 1\mathbb{I}(|u| \le 1)$. This kernel function has compact support. The constants c are selected by the so-called rule of thumb. To achieve the uniform consistency of estimators, we need to consider the bandwidths. For the choice of the bandwidths, we have $h_W = c_W[logT/T]^{1/(2R+3)}$, $h_w = c_w[logT/T]^{1/(2R+4)}$ $h_R = c_R[logT/T]^{1/(2R+3)}$, $h_r = c_r[logT/T]^{1/(2R+4)}$ and $h_x = c_x[logT/T]^{1/(2R+3)}$. The constants c are chosen by the so-called rule of thumb. We set $R = 1$. Thus, we have $h_W = 2.978\times1.06\times\hat{\sigma}_W T^{-0.2}$, $h_R = 2.978\times1.06\times\hat{\sigma}_R T^{-0.2}$, $h_w = 2.978\times1.06\times\hat{\sigma}_W T^{-1/6}$, $h_r = 2.978\times1.06\times\hat{\sigma}_R T^{-1/6}$ and $h_x = 2.978\times1.06\times\hat{\sigma}_x T^{-1/6}$ where σ is the standard deviation of each variable.

We need to obtain the functional form of $V(\cdot)$ to compute the quality levels and social welfare under the counterfactual scenarios. $V(\cdot)$ is unobservable, while the data set includes information on the reserve price r, the cost overrun P and the quality score of work Q. For the simplicity of analysis, we assume $V(Q) = a \log Q$ where a is a parameter. Assuming the relation between $V(Q)$, r and $E(P)$ as $V(Q) = a \log Q = r + E(P)$, we calculate a in each auction by using the information from the data set.[7]

7 Estimation Results and Counterfactual Simulation

7.1 Estimation Results

Table 6 shows the estimation results for the cost function of the quality level. Table 6 indicates that the fixed cost α holds the large proportion of the estimated cost on average. The cost parameter of the cost function θ is very small with an average value of 2498.53 relative to the magnitude of the fixed cost with the average value of 94.75 million. The fixed cost accounts for about 84% of the total cost on average. Hence, the shape of the cost function seems to be very smooth. The figure of the cost function is shown in Figure 2.

We observe the differences of the functional forms of the costs across the sizes of contracts. Table 6 reports the net values of the cost parameters (θ) and fixed costs (α) across the sizes of contracts. Table 6 shows that the average values of the cost parameters and fixed costs normalized by the reserve prices. The characteristics of the normalized cost parameters and fixed costs are different across the sizes of contracts. For the smallest-scale contract which is worth less than 50 million yen, the average of cost parameters is the largest with the value of 0.0001. On the other hand, for the largest-scale contract which is worth more than 200 million yen, the average cost parameter is the smallest with the value of $9.91E-06$. The proportion of the fixed cost to the total cost is about 67% for the smallest-scale contract. For the largest-scale contract, the fixed cost holds about 94% of the total cost on average.

7.2 Counterfactual Experiments

We consider the counterfactual experiments. When the government reduces the cost overrun, the quality level and the cost of the winning bidder are given by:

[7] The observed secret reserve price is assumed to be equal to the government's private value. This assumption is used to compute the optimal reserve prices. See Li and Perrgne (2003) and Flambard and Perrigne (2006).

$$Q^{**}(\hat{\theta}) = \frac{kE(\gamma)}{2\hat{\theta}} \qquad \text{and} \qquad c = C(Q^{*}(\hat{\theta}_{1:N}), \hat{\theta}_{1:N}) = \hat{\alpha} - \frac{k^2 E(\gamma)^2}{4\hat{\theta}_{1:N}}$$

where $\hat{c}$, $\hat{\theta}$ and $\hat{\alpha}$ are estimated values. We then obtain social welfare ($V(Q^{**}(\theta)) - C(Q^{**}(\theta), \theta)$) in this environment.

Table 7 shows the results of the counterfactual scenario. When the cost overrun is decreased by 5%, the quality score of work is 69.61 and the welfare loss is 0.4 million yen per contract on average. When the government reduces the cost overrun by 25%, the quality score of work is 54.95 and the welfare loss is 3.5 million yen per contract on average. When the cost overrun is discounted by 50%, the quality score of work is 36.64 and the average welfare loss is 12.7 million yen per contract. Moreover, when the government abolishes the cost overrun (99% cut of the extra payment), the quality score of work is almost 0 and the average welfare loss takes a negative value. We find that the presence of the cost overrun is effective to ensure the quality of work and social.

We observe the differential impacts on the quality of work and the welfare gain across the sizes of contracts when the cost overrun is reduced. For small-scale contract, the welfare gain arises when the cost overrun is decreased by 5% and 25%. The average of welfare gain is 0.6 million yen (1.8 million yen) per contract, while the quality score of work is decreased by 5% (25%). With regard to the contracts with the value of the size of a project worth 50 million yen or more, when the cost overrun is discounted, social welfare is decreased.

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8 Conclusion

In this paper, we develop a structural auction model in which the cost overrun arises and the selected bidder determines the quality level during construction. In this model, the government proposes a linear payment schedule which consists of its bid and the cost overrun. The cost overrun is assumed to be an incentive scheme to ensure the quality of work. Hence, the structural auction model used for our analysis combines and the adverse selection (uncertainty at the time of bidding) and the situation similar to the moral hazard (the choice of the quality of work during construction). Using a unique dataset including the final payment and information on the quality of work evaluated at the time of completion, we identify and estimate the structural model. In counterfactual experiments, we show that when the cost overrun is reduced, the quality of work and social welfare tend to be decreased.

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9 Appendix

The data of geological conditions is constructed based on Wakabayashi, et al. (2005) and the data publicly available from the MLIT website. The GIS (Geographic Information System) data produced by Wakabayashi, et al. (2005) is 1 kilometer mesh data and is constructed based on AVS30 that is an index of the shaking of surface ground when earthquake hits.[8] There are four geological factors that affect the execution of works in public-works projects according to Ikeda (1986): the condition of surface ground, the condition of faults, the condition of landslides and the condition of liquefaction. The variable of surface ground condition represents the surface geological (topographical) condition within 1 kilometer radius of the project location. This variable is negatively correlated with the softness of surface ground due to the characteristic of AVS30. This variable takes from 100 (bad surface ground condition) to 740 (good surface ground condition). The variable of faults measures the condition of faults within 1 kilometer radius of the project location. This variable takes from 0 (no risk from faults) to 1 (risk from faults). The variable of landslide represents whether the area within 1 kilometer radius of the project location is affected by landslides. This variable also takes from 0 (no risk for landslides) to 1 (risk for landslides). The variable of liquefaction measures the condition of liquefaction within 1 kilometer radius of the project location. This variable takes from 1 (high risk for the liquefaction) to 4 (low risk for the liquefaction).

The variable of the meteorological condition is constructed using publicly available data from the Japan Meteorological Agency website. In Japan, there are totally about 1000 meteorological observatories. We use the data which is the closest observatory to the project site. The variable of precipitation represents the average amount of rainfall around the project location in each year. The variable of minimum temperature is the minimum temperature around the project location in each year. The amount of rainfall is considered to be related to the condition of surface grounds. The minimum temperature also affects the condition of work through the condition of concrete. We use the data which is the closest observatory to the project location.

We provide the construction materials prices and the income level around the project location.[9] The variable of construction materials prices consists of ten kinds of representative construction materials prices to perform public-works projects. It is composed of the prices of steel, the secondary product of concrete, fresh concrete, cement, aggregate, asphalt mix, bituminous material, special steel and temporary material. This variable is monthly calculated by Paasche index of these prices and con-

[8]The Cabinet office exploits this measure to make a map to deal with earthquakes.

[9]For the construction materials prices, we use the data constructed by Economic Research Association. The data of and the employment rate and the income level is obtained from the data of population and households provided by Statistical Bureau.

structed at each regional bureau level. The variable of the income level is measured on the basis of the data of the average annual income per taxpayer at about 1800 cities in Japan. In order to construct this variable, we use the data of the city that is the nearest to the project location.

Table1: Small-business Set Aside

		Open Auctions		Invited Auctions	
Size of a contract	Rank of a responsible bidder	Number of potential participants	Number of contracts	Number of invited bidders	Number of contracts
A	A	440 (89 %)	66 (94 %)	-	-
	B	22	2	-	-
	C	30	3	-	-
	sum	492	71	-	-
B	A	0	0	9	3
	B	0	0	466 (92 %)	52 (87 %)
	C	0	0	32	5
	D	-	-	0	0
	sum	0	0	507	60
C	A	-	-	36	2
	B	-	-	409	48
	C	-	-	27163 (98 %)	2585 (98 %)
	D	-	-	41	4
	sum	-	-	27649	2639
D	A	-	-	0	0
	B	-	-	0	0
	C	-	-	280	28
	D	-	-	4669 (94 %)	481 (94 %)
	sum	-	-	4949	509

Note: For this information, see http://www.mlit.go.jp/page/kanbo01_hy_003695.html.

Table2: Summary Statistics

Variable	Mean (Standard deviation)
Reserve price	1.20E+08
	(1.54E+08)
Appraisal value	9.12E+07
	(1.20E+08)
Relative winning bid	0.91
	(0.09)
Number of actual bidders	9.10
	(3.22)
Relative final payment	1.13
	(0.32)
Cost overrun	0.24
	(0.31)
Quality score of work	73.13
	(4.66)
Contractual length	198.58
	(83.21)
Delay in Completion	0.44
	(0.64)
Number of potential bidders	9.94
	(3.23)
Material price	103.90
	(5.90)
Income	2988983
	(405670)
Precipitation	1556.09
	(544.99)
Minimum temperature	2.23
	(3.02)
Surface ground	436.84
	(181.66)
Fault	0.06
	(0.16)
Landslide	0.12
	(0.26)
Liquefaction	3.35
	(0.66)
Sample size	1350

Note: Standard deviations are in parentheses.

Table3: Regression Results on the Relation between the Quality Score of Work and the Cost Overrun

Dependent variable Estimator	Log of cost overrun OLS	Dependent variable Estimator	Log of cost overrun IV
Quality score of work	0.0052*** (0.0013)	Quality score of work	0.2119** (0.0875)
Sample size	1350	Sample size	1350
R-squared	0.0568	R-squared	-

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are in parentheses. All estimation models include a constant term, auction-level characteristics, the variables of geological conditions, the variables of meteorological conditions, the variable of economic environment and 11 monthly dummy variables.

Table4: Regression Results on Winning Bids and Relative Winning Bids

Dependent variable Estimator	Log of winning bid OLS	Dependent variable Estimator	Log of winning bid OLS
Number of potential bidders	-0.0019* (0.0010)	Log of number of potential bidders	-0.0113 (0.0075)
Sample size	1350	Sample size	1350
R-squared	0.9822	R-squared	0.9821

Dependent variable Estimator	Relative winning bid OLS	Dependent variable Estimator	Relative winning bid OLS
Number of potential bidders	-0.0014* (0.0009)	Log of number of potential bidders	-0.0087 (0.0064)
Sample size	1350	Sample size	1350
R-squared	0.0562	R-squared	0.0552

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are in parentheses. All estimation models include a constant term, auction-level characteristics, the variables of geological conditions, the variables of meteorological conditions, the variable of economic environment and 11 monthly dummy variables.

Table5: Regression Results on Winning Bids and Relative Winning Bids

Dependent variable Estimator	Log of winning bid OLS	Dependent variable Estimator	Relative winning bid OLS
n1	0.0258	n1	0.0249
	(0.0374)		(0.0295)
n2	-0.0407	n2	-0.0391*
	(0.0278)		(0.0226)
n3	-0.0934***	n3	-0.0849***
	(0.0299)		(0.0243)
n4	-0.0617***	n4	-0.0594***
	(0.0218)		(0.0172)
n5	-0.0444**	n5	-0.0408**
	(0.0203)		(0.0164)
n6	-0.0571**	n6	-0.0522***
	(0.0234)		(0.0187)
n7	-0.0487**	n7	-0.0427**
	(0.0227)		(0.0179)
n8	-0.0455**	n8	-0.0416***
	(0.0201)		(0.0162)
n9	-0.0579***	n9	-0.0511***
	(0.0218)		(0.0171)
n10	-0.0479***	n10	-0.0457***
	(0.0164)		(0.0124)
n11	-0.0547***	n11	-0.0505***
	(0.0183)		(0.0141)
n12	-0.0772***	n12	-0.0676***
	(0.0234)		(0.0175)
n13	-0.0523***	n13	-0.0481***
	(0.0199)		(0.0156)
n14	-0.0710***	n14	-0.0604***
	(0.0249)		(0.0195)
n15	-0.0745***	n15	-0.0660***
	(0.0277)		(0.0230)
n16	-0.1334***	n16	-0.1121***
	(0.0357)		(0.0291)
n17	-0.0602*	n17	-0.0527**
	(0.0275)		(0.0231)
n18	-0.0749**	n18	-0.0667**
	(0.0336)		(0.0288)
n19	-0.0615*	n19	-0.0543*
	(0.0338)		(0.0289)
n20	-0.1055**	n20	-0.0989**
	(0.0473)		(0.0446)
n21	0.0438	n21	0.0383
	(0.0321)		(0.0284)
n26	-0.3565***	n26	-0.2850***
	(0.0217)		(0.0174)
n30	-0.0358**	n30	-0.0359**
	(0.0169)		(0.0143)
Sample size	1350	Sample size	1350
R-squared	0.98	R-squared	0.08

Note: *** denotes statistical significance at the 1% level, ** statistical significance at the 5% level and * statistical significance at the 10% level. Robust standard errors are in parentheses. All estimation models include a constant term, auction-level characteristics, the variables of geological conditions, the variables of meteorological conditions, the variable of economic environment and 11 monthly dummy variables.

Table6: Estimation Results on the Cost Function

Contract size	Sample size	Estimated cost ($\hat{c}$) (yen; mils)	$\hat{\theta}$	$\hat{\alpha}$ (mils)	$\frac{\hat{\theta}}{reserveprice}$	$\frac{\hat{\alpha}}{reserveprice}$	$\hat{\alpha}/\hat{c}$ evaluated at 70
Total	1313	81.50	2498.54	94.75	3.54E-05	0.88	0.84
~50 million yen	182	16.97	2556.31	29.27	0.0001	1.12	0.67
50~100 million yen	543	53.86	2462.80	66.95	3.34E-05	0.88	0.83
100~200 million yen	488	108.81	2499.35	122.43	1.69E-05	0.80	0.89
200 million yen~	100	215.74	2583.49	303.05	9.91E-06	0.82	0.94

Table7: Results on Counterfactual Simulation

Quality	Current policy	5% off	25% off	50% off	99%cut
Total	73.27	69.61	54.95	36.64	0.73
~50 million yen	70.09	66.59	52.57	35.05	0.70
50~100 million yen	73.34	69.67	55.00	36.67	0.73
100~200 million yen	74.18	70.47	55.63	37.09	0.74
200 million yen~	74.28	70.57	55.71	37.14	0.74

Social welfare	Current policy	5% off	25% off	50% off	99% off
Total	32.20	31.82	28.61	19.52	-104.80
~50 million yen	11.40	11.96	13.20	11.98	-33.77
50~100 million yen	22.22	22.21	21.03	15.47	-74.39
100~200 million yen	44.23	43.40	38.13	25.41	-135.03
200 million yen~	65.97	63.64	51.39	26.57	-251.73

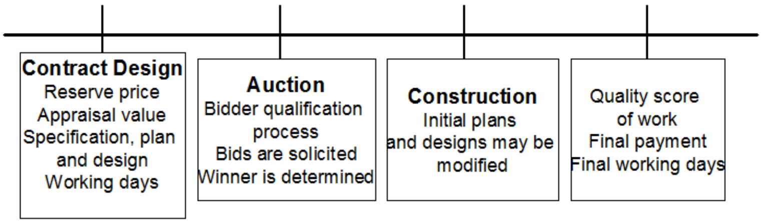

Figure 1: Public-works Procurement

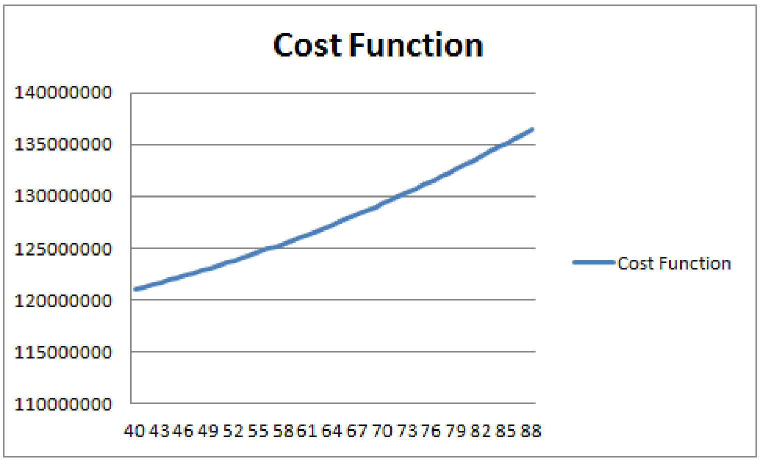

Figure 2: The Shape of Cost Function