Bidding for Contracts under Uncertain Demand: Skewed Bidding and Risk Sharing

Yao Luo* Hidenori Takahashi†

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Abstract

We investigate the roles of risk-allocation on firm behavior and contract outcomes. With a sample of Fixed-Price (FP) and Unit-Price (UP) contracts, evidence indicates that procurers' contract choice depends on unobserved project heterogeneity, consistent with the procurers' belief that UP performs well for risky projects. Bidding strategies under UP indicates firms' opportunistic behavior: firms that anticipate a large cost-overrun bid aggressively in expectation to get compensated via cost-overrun. We estimate a model of bidding for contracts. A simulation result indicates switching from UP to FP (resp. FP to UP) would reduce the procurement cost when project risk is small (resp. large).

*Mailing Address: Department of Economics, University of Toronto, 150 St. George Street, Toronto, Ontario, Canada. Email: yao.luo@utoronto.ca.

†Mailing Address: Department of Economics, University of Mannheim, L7, 3-5, Mannheim, 68131, Germany. Email: htakahas@mail.uni-mannheim.de. We would like to thank Victor Aguirregabiria, Andre Boik, Francesco Decarolis, Isis Durrmeyer, Takakazu Honryo, Ismael Mourifié, Kathleen Nosal, Andrea Pozzi, Junichi Suzuki, Yuya Takahashi, and Naoki Wakamori for extensive discussions. We are also greatful with the FDOT's support for generously providing procurement data.

1 Introduction

Procurements of infrastructure projects involve significant amount of uncertainty: unexpected changes in the plan during the implementation of a project. Which contracting party should be responsible for such project risk is a topic of heated debate.[1] On the one hand, a procurer may face a higher cost of procurement via allocating project risk to its contractor if the contractor incorporates the cost of risk in its contracting price. On the other hand, a procurer may induce excessive cost-overruns by being responsible for the project risk if the contractor behaves opportunistically to get compensated through cost-overruns. Despite the empirical relevance of risk-allocation and the prevalence of such contracting environment, the empirical literature on this issue has been scarce.

We study so-called Fixed-Price contracts (FP) and Unit-Price contracts (UP), hand-collected from the Florida Department of Transportation (FDOT), to investigate the roles of risk-allocation and contractual arrangements on firms' behavior and contracting outcomes.[2] Projects are procured in the form of auctions. Contractual arrangements affect competition outcomes through changes in effective project risk and the incentive to win a contract, which in turn affects potential contractors' pricing and entry decisions in the competition for a contract.[3]

It is FDOT's belief that FP (.resp UP) contract should be used for a project with a small (.resp large) project risk.[4] Under UP contract, FDOT's engineers first estimate the quantity of each construction item required for the project, and every bidder submits a unit-price for each item. Then, the FDOT's estimates are multiplied by bidders' unit-prices, and summed across all items to determine the score for each bidder. The winner in a UP is determined by the lowest score, and the contractor is paid the score amount upon the completion of the project if the estimated quantity is actually used during the construction phase of the project. If there is any quantity change on any of the contracted items: items specified by the FDOT

[1]Resulting cost-overruns could reach millions of dollars if not billions. For example, the Boeing Dreamliner programme, announced in 2003, was supposed to cost 6 billion dollars. The final bill was about 32 billion dollars. Another example from Germany is a construction of Berlin Brandenburg Airport, which was estimated to cost one billion euros initially. The project ended up costing 6 billion euros.

[2]FP contracts are widely used in public procurements, including procurement of military weapons, public transport, operation of water facilities, and electricity. UP is widespread in construction procurements, including highway contracting, pipeline construction, defense procurement, and procurement projects supported by World Bank. UP is also used in timber auctions as in Athey and Levin (2001).

[3]The FDOT procures small infrastructure projects through either UP or FP contracts. Large projects are procured via so-called Design-Build Auctions.

[4]FDOT's project guidelines explicitly list the tasks suited for FP contract and UP contract. See Figure 1.

and bid on at the time of bidding, the contractor is obliged to provide the additional materials at its unit-price.[5] Under FP contract, on the other hand, firms submit a single price bid for an entire project and the firm with the lowest price bid contracts with the FDOT.[6] The contractor receives its own price bid upon completion. That is, construction items are provided at the cost of a contractor regardless of the quantity required to complete the project.

We contribute to the literature on empirical contract and auction in various dimensions. First, we provide evidence suggesting that the selection of contractual arrangement depends on unobserved project heterogeneity. The literature on procurement auctions has largely ignored unobserved differences between the two contractual arrangements and occasionally pooled these two contract formats based on the observation that OLS comparison does not suggest any significant differences in bidding strategies across the contractual arrangments. Second, we show evidence of firms' opportunistic behavior. UP contracts mitigates costly ex-post renegotiation by fixing the price of items ex-ante, but the firms strategically decide on their unit-price bids. We show that firms bid high on items that overrun is expected in expectation to get compensated through overrun while they bid low on items with no pay adjustments (i.e., skewed bidding). Lastly, we construct, identify, and estimate a model of bidding for contracts, which nests the two contractual arrangements and allows for a variety of counterfactual experiments. To the best of our knowledge, skewed bidding in UP contracts has been known to exist, but no paper identifies or estimates a structural model of UP contracts in the presence of skewed bidding.

We provide suggestive evidence that an FDOT's project manager's contract choice depends on unobserved project heterogeneity in a way consistent with the FDOT's belief. On the one hand, FDOT's project manager's decision to use FP contract is negatively correlated with scores since a bidder's cost under FP contract is likely increasing fast in unobserved project risk, and FDOT's project manager is less likely to use FP contract when a project involves much uncertainty. On the other hand, FDOT's project manager's decision to use UP contract is weakly positively correlated with scores if UP contract is robust to project risk. We show that contract choice is strongly negatively correlated with bids under

[5] In the case of quantity change on uncontracted items: items not specified at the time of bidding and not bid on, the contracting parties renegotiate the prices in both FP and UP. UP contract differs from Cost-Plus contract in that pay adjustment due to change in the plan is fixed at the time of auction, and therefore leaves no room for renegotiation for the contracted items.

[6] Quantity estimates are also provided in FP contract.

FP contracts but not under UP contracts using exogenous variation in contract format choice due to FDOT's backlog level. FDOT's project managers are likely to choose FP contract when the FDOT is heavily backlogged since UP contract requires much department personnel to keep track of items used in implementation. We argue that the FDOT's backlog level has nothing to do with bidders' unobserved costs conditional on bidders' backlog level, satisfying the exclusion restriction.

We show suggestive evidence that UP contracts induce bidders' opportunistic behavior through skewed bidding. A bidder has an incentive to bid high on underestimated items and bid low on overestimated items since positive ex-post adjustments increase the bidder's revenue while negative ex-post adjustments reduce the bidder's revenue. Since bidders differ from each other in quantity estimates, the bidder with the highest estimate has the largest incentive to win the contract. We show that bidders who skew their unit-price bids are much more likely to win the contract. The unique winner selection mechanism of UP contract allows us to isolate unobserved project heterogeneity because UP contracts induce all bidders to act ex-ante and not ex-post where the econometrician does not observe how non-winning bidders would have behaved ex-post if they had won.

Backed by our empirical evidence, we construct a model of bidding for a contract, nesting the two contractual arrangements. The model here extends Ewerhart and Fieseler (2003) by introducing multi-dimensional bidder heterogeneity, risk-aversion, and endogenous entry. From an empirical point of view, it is important to allow for multi-dimensional bidder heterogeneity since bids are multi-dimensional. It is difficult to rationalize the observed distribution of bids in the framework of uni-dimensional bidder heterogeneity since multi-dimensional bidding strategy would be a function of a uni-dimensional type. Risk-aversion explains why bidders do not completely skew their bids and rationalizes the FDOT's belief.[7] The model captures the key trade-off that the procurer faces in choosing a contract format in the presence of project risk. On the one hand, UP allows bidders to hedge against project risk by forming a portfolio of unit-price bids while FP execerbates bidders' costs by providing no way to hedge against project risk. On the other hand, UP induces skewed bidding which may result in a higher procurement cost through the selection of inefficient contractor. Endogenizing entry decision of bidders is important as changing contractual arrangements affects not only bidding behavior but also the level of competition through entry.

[7] On theoretical grounds, firm risk aversion is explained by imperfect capital markets so that procurement-specific risks matter to firms (Samuelson, 1986).

In particular, UP contract brings in more competition than FP contract since UP introduces an incentive to earn profit through cost-overrun and a tool to hedge against project risk, none of the which exists under FP contract. We numerically demonstrate that FP (resp. UP) contract performs well for projects with low (resp. high) project risk, and show that our model is consistent with a number of empirical findings.[8] We show that the model is semiparametrically identified from UP contracts, which allows us to evaluate a variety of counterfactual contractual arrangements.

We find significant negative correlation between the bids and the decision to choose FP contract while we find insignificant positive correlation between bids and the decision to choose UP contract. We interpret this finding as evidence that FP contract is less likely to be used when a project involves much project risk, and UP contract is robust to project risk. Bidders are substantially heterogeneous in the portfolio of unit-price bids, and skewed bidding is economically and statistically very significant. Counterfactual experiments through the estimated model, which accounts for unobserved project heterogeneity in project risk, suggest that UP contracts perform well at least for those projects in the data that were procured through UP contract. Switching from UP to FP would significantly increase the procurement cost.

Despite its practical relevance, empirical work on evaluating the performance of contractual arrangements remain scarce. One of the few related empirical work is Decarolis (2014), which compares contracts awarded via first price auctions and average price auctions. First-price auctions are found to have a perverse effect on ex-post contract performance relative to average price auctions. Bajari et al. (2013), which also investigates UP contracts, shows that skewed bidding is not economically signficant, which contradicts with our finding. The empirical discrepancy is likely to come from institutional differences across the state departments of transportations. Bajari et. al. (2013) use procurement data from California Department of Transportation where the contracting price can be renegotiated if quantity adjustment is more than 25% of original estimated quantity while the threshold is 125% for the projects dealt by the FDOT.[9] On top of allowing for comparison of FP with UP contracts, our model differs from Bajari et. al. (2013) in that we allow for expected quantity of work items to differ across bidders and bidders face uncertainty

[8]Our model is consistent with the observations that i) UP contract is robust to project risk, ii) scores are much more dispersed in FP than UP, iii) composition of unit-price bids shows a substantial amount of within-auction variation, and iv) bidders skewing their bids are more likely to win the contract.

[9]For details, see Section 4 at http://mcraemetcalf.com/wp-content/uploads/2016/07/FDOT-2016eBook-Standard-Specifications.pdf

in actual quantity of work items. Relaxing these assumptions explains why the composition of unit-price bids varies much in any given auction and also explains why bidders do not completely skew their bids to hedge against project risk.

The rest of the paper is organized as follows. Section 2 presents the literature and Section 3 describes the data and the procurement procedures under both FP and UP. Section 4 provides evidence that the procurer's choice of contract depends on unobserved project risk together with evidence of skewed bidding. Section 5 presents the model of bidding for a contract. Section 6 shows semiparametric identification of the model and Section 7 provides estimation steps together with the results. Section 8 provides counterfactual experiments and shows that UP works better than FP when project risk is large while FP works better than UP when project risk is small. Section 9 concludes.

2 Related Literature

This paper is not the first to study skewed bidding in UP contracts. The most closely related work to ours is Ewerhart and Fieseler (2003), who study bidder behavior in a UP contract in independent private value framework. In their framework, uncertainty in ex-post item quantity does not matter to bidders as bidders are assumed to be risk-neutral. They show that bidders with a large estimate on the ex-post quantity has a larger incentive to win the contract and therefore, bid more aggressively to win the contract, which results in skewed bidding. We introduce bidder risk-aversion and endogenous entry decision into the framework of Ewerhart and Fieseler (2003) as bidders do not completely skew their bids empirically, and contract formats significantly affects bidders' expected payoffs, which in turn influences bidders' entry decisions.

Athey and Levin (2001) finds evidence of skewed bidding in the U.S. forest service timber auctions. They also find that bidders do not completely skew their bids, which is consistent with bidder risk-aversion. Our model differs from Athey and Levin (2001) in that we apply private value framework while they assume common value framework.

This paper is more broadly related to the litarture on contracting via auctions. The seminal work in the literature on procurement contract through auction is McAfee and McMillan (1986), which compares the performance of fixed-price contract and cost-plus contract in an incomplete contract setting. They show that the optimal incentive contract is linear in bid and ex-post realized costs. Bajari, Houghton, and Tadelis (2014) structurally estimates a model of UP in an incomplete contract setting since the majority of ex-post adjustments originates from uncontracted items in their environment. Our framework differs from the strand of incomplete contract literature in that we consider a complete contract setting since the majority of ex-post adjustments in Florida originates from the adjustments on contracted items. Lewis and Bajari (2011) examines the time incentive effect Lewis and Bajari (2011), Lewis and Bajari (2014), Ann and Tang (2015) Decarolis (2014), Perrigne and Vuong (2011).

Our work is also related to the vast literature on the identification and estimation of auction models with risk-averse bidders and endogenous entry.[10] Guerre, Perrigne, and Vuong (2009) shows that risk-averse bidders' utilitity function and the distribution of private valuations can be nonparametrically identified via exclusion restriction and observed bids from first-price auctions. Campo, Guerre, Perrigne, Vuong (2011) shows that risk-averse bidders' utility function and the distribution of private values are semiparametrically identified under a conditional quantile restriction on the distribution of bidders' private valuation and a parametrization of the bidders' utility function. Li and Zheng (2009) estimates three competitng endogenous entry models in procurement auctions and finds that the model with a common entry cost where bidders draw their private costs upon entry best fits the data.

3 Institutional details and data

This section describes the procurement procedure, FDOT's project guidelines, and the data with descriptive analyses. Description of auction procedure provides information on who makes what decisions at what point in time. The FDOT's project guidelines indicate why one should be concerned about selection of a contract format. Lastly, we provide OLS comparison of bidders' behavior and project outcomes across the two contractual arrangements.

[10]Bidding behavior consistent with risk-aversion is confirmed in both empirical and experimental studies (e.g., Cox, Smith, and Walker, 1988; Athey and Levin, 2001; Goeree, Holt, and Palfrey, 2002). Bajari and Hortacsu (2005) also show that a structural model with risk aversion provides the best fit to some experimental data among a set of competing models.

3.1 Procurement procedure

The FDOT consists of seven district offices that procure infrastructure projects independently. Each district office announces a list of projects every month. The set of procured projects in any month is determined by the FDOT's project managers together with various department personnel. The procurement procedure can be decomposed into a design phase, followed by an auction and a construction phase.

In the design stage, FDOT's in-house engineers specify the plan/design of a project, which includes an engineer's estimate of the project cost, and a quantity estimate on each construction item. The project manager then decides whether to procure the project using FP or UP. A project guideline pusblished by the FDOT explicitly states that FP contract should be used for "projects with low risk of unforseen conditions".[11] Figure 1 is extracted from the guideline, which lists the types of projects FP contracts are suited and not suited. Essentially, the guideline states that FP contract should be used for simple projects while UP is used otherwise. One to two months prior to project letting, the FDOT posts an advertisement on-line which lists information about the project location, description of work, expected contract duration, and engineer's estimate of the project cost.

The project enters the auction phase. If a project is procured through UP, every interested firm submits a unit-price for each item given the quantity estimate. For example, if the FDOT's in-house engineer estimates that 10 units of electronic message signs need be implemented, a bidder submits a dollar amount describing how much one unit of the 10 electronic message signs will cost. Then, these unit-price bids are multiplied by the estimated quantities, and summed across all the construction items to derive a score. The score is then used to rank all the participating bidders, and the bidder with the lowest score wins the contract in UP. The contractor is obliged to provide the contracted items at its unit-price. If a project is procured through FP, on the other hand, every interested firm submits a single price bid, which is the score in FP, and the firm with the lowest price bid wins the contract. The firm is obliged to provide the project at its price bid amount unless significant change in the contract occurs during the construction phase while it obtains flexibility in the choice of the set of construction materials.[12]

The auction phase is followed by a construction phase. Project implementation is closely monitored by a construction engineering inspector of the FDOT. If there is no change in the construction plan, the

[11] Lump-Sum Project Guideline is found at http://www.fdot.gov/roadway/bulletin/ls010402.pdf. We call lump
[12] Quantity estimates are also provided in FP contracts.

contractor receives its own bid upon delivery of the project in both UP and FP contracts. Under UP contract, if the FDOT project manager finds a need for some adjustments in the construction plan, the payment to the contractor is adjusted based on the contractor's unit-price bids and quantity adjustment. For example, if labour is contracted on per-day basis, then extra days of work multiplied by contractor's unit-price on labour component is paid to the contractor. More than 95% of these adjustments are initiated by the FDOT, and not contractors. Under FP contract, there is no adjustment in payment arising from changes on contracted items.

Adjustments could also occur on uncontracted items. For example, storm during construction phase may damage construction materials, and repair may be needed. In this case, the FDOT's project manager files a claim for the extra work describing the associated cost, time extension required to implement the change, and the reason for the change. These additional uncontracted tasks could involve negotiation, and the price for these tasks is determined the same way in FP and UP contracts. Figure 1 shows the distribution of the share of ex-post adjustments on contracted items in total adjustments. It turns out that more than 80% of adjustments come from adjustments on contracted tasks.

Table 1: Share of Contracted Items in Ex-post Adjustments under UP contracts

Mean	**5pctl**	**25pctl**	**50pctl**	**75pctl**	**95pctl**
.801	.158	.608	1	1	1

We conduct a simple simulation exercise to demonstrate the extent of ex-post adjutments on the winner selection process. To conduct the simulation exercise, we assume that (i) bidders' behavior is fixed (i.e., unit-price bids are given by the data), (ii) all the participating bidders would experience exactly the same quantity adjustments upon winning a contract, and (iii) the auctioneer could select the winner based on the final payment rather than the score. That is, the auctioneer foresees the actual quantity at the time of auction. We find that 10.3% of UP contracts in the data would have had a different winner than the actual winner if the auctioneer had been able to select the winner based on the final payment to the contractor.[13] We relax assumption (i)-(iii) later in the structural modeling section, but this simple exercise demonstrates the extent of ex-post adjustments.

[13]The probability of winner switch in FP is not affected by this experiment by construction.

A typical concern raised in the analysis of cost-overrun is the possibility of default. Contractor's default is particularly relevant in the context of the analyses here since FP contract may involve more frequent default than UP contract if contractors are unable to supply extra work or items required to complete the project. During the sample period, 25 projects (1.3% of the sample size) that were procured through either FP or UP contract were defaulted.[14] The majority of these defaults are not due to adjustment in the project plan but due to contractors failing to perform the work in accordance with the terms of the contract. Another possibility for default is the limited district office project budget. If a district office is unable to make additional payment for extra work or items under UP, then project managers may decide not to complete the project due to insufficient fund. It turns otu that the FDOT district offices pool their annual budget across projects and make sure that all the procured projects are completed.[15]

Examples of projects that may be good Lump Sum contracting candidates:

- Bridge painting
- Bridge projects
- Fencing
- Guardrail
- Intersection improvements (with known utilities)
- Landscaping
- Lighting
- Mill/Resurface (without complex overbuild requirements)
- Minor road widening
- Sidewalks
- Signing
- Signalization

Examples of projects that may not be good Lump Sum contracting candidates:

- Urban construction/reconstruction
- Rehabilitation of movable bridges
- Projects with subsoil earthwork
- Concrete pavement rehabilitation projects
- Major bridge rehabilitation/repair projects where there are many unknown quantities.

Figure 1: Page Extracted from FDOT's Project Guidelines

[14]We have 22 out of the 25 defaulted projects in our sample and 13 (.resp 9) projects were procured through UP (.resp FP) contract.

[15]The FDOT requires every bidder submit a surety bond, which describes which firm would take over an incomplete project in the case of contractor's default. FDOT project managers state that every project is completed without exception. We also control for annual district budget amount in the following regression analyses.

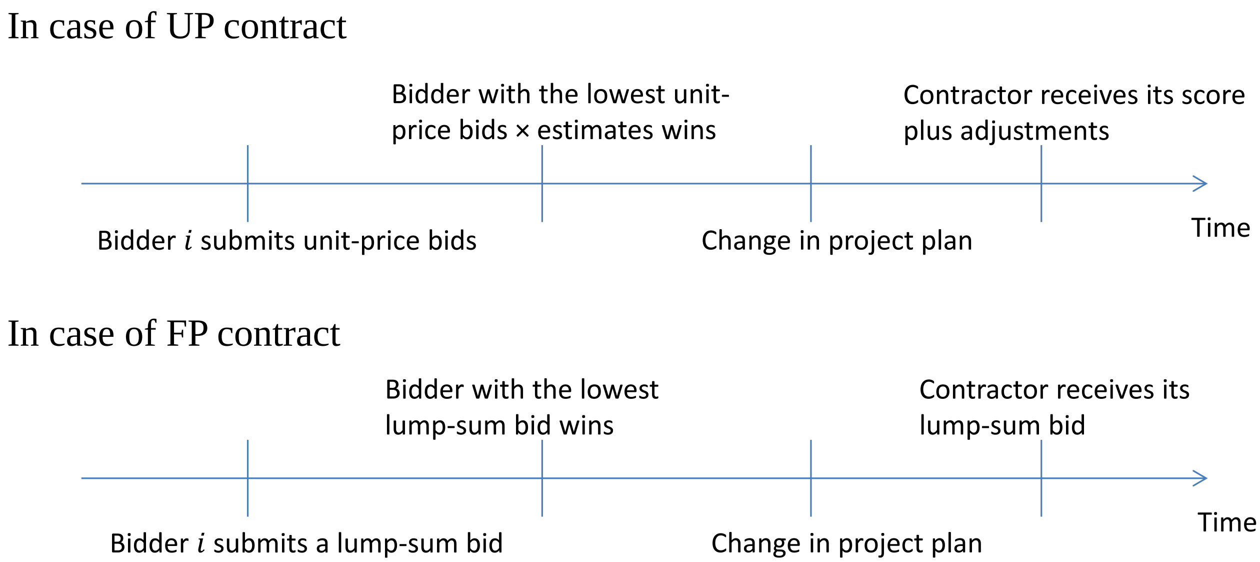

Figure 2: Timeline of Events

3.2 Data and Descriptive Analyses

We investigate a sample of infrastructure projects procured via FP or UP contracts between year 2003 and 2014 by the FDOT.[16] The data contain rich information, including all participating bidders' price bids (every unit-price bid for UPs), FDOT's engineer's cost estimates, quantity estimates in UP contracts, final payment to contractors, project location, description of work, identities of both participating and non-participating bidders. We define participating bidders as those plan holders that submitted bids and non-participating bidders as those that did not.

The FDOT's estimate office constructs cost estimates based on historical unit-price bids.[17] The estimates are constructed in the same way in FP and UP projects. As work description provides information about the type of projects (i.e., road repair, bridge construction, etc), but significantly vary across projects, we extract tasks from these work description and define a project type as a linear combination of these tasks.[18]

[16]The sample consists of relatively small projects since the FDOT uses another mechanism, so-called Design-Build auctions, for large projects. The average contracting price for Design-Build auctions during the sample period is about 14 million dollars.

[17]Engineer's cost estimate and expected contract duration are explicitly given in the advertisement of a project, and therefore these project characteristics are known to bidders at the time of bidding.

[18]For example, we create an indicator variable equal to one if a work description contains a word "milling", another indicator variable equal to one if a work description contains a word "widening", and so on. In total, we have 18 tasks which

Table 2: Summary Statistics of Fixed-Price and Unit-Price Contracts

	FP					UP				
Variable	**Mean**	**Std.**	**Min.**	**Max.**	**N**	**Mean**	**Std.**	**Min.**	**Max.**	**N**
Winning Score ($1,000)	1601	2052	14.0	14500	628	3957	7510	7.51	148000	1260
Engineer's Cost Estimates ($1,000)	1884	2321	23.3	16600	628	4775	9095	12.7	164000	1260
Expected Contract Duration (# of Days)	117	67.8	30	550	628	236	196	15	2034	1260
Final Payment to Contractor ($1,000)	1652	2126	14.3	14400	628	4142	8095	7.50	159000	1260
Ex-Post Pay Adjustment ($1,000)	51.0	177	-1640	1851	628	185	750	-2000	11200	1260
# of Participating Bidders / Auction	4.32	2.39	1	15	628	4.98	2.67	1	19	1260
# of Plan Holders / Auction	36.2	17.4	1	82	628	41.7	24.5	1	159	1260

Winning score is the winner's price bid amount in FP and the sum of unit-price times estimated quantity in UP.

The summary statistics of the key variables in UP and FP contracts are presented in Table 2. On average, a fewer number of bidders participate in FP than in UP. UP is used for relatively large projects and is expected to take a longer time to complete than FP. We also see that FP projects are less susceptible to cost overruns, and the average cost-overrun in UP is six times greater than that of FP projects.

OLS outcomes are presented in Table 3. We consider four dependent variables, entry, log(score), winner's log(score), and log(final payment). A potential bidder is considered to enter an auction if a plan holder submits a bid. A score in FP is equivalent to a price bid while a score is the unit-prices times estimated quantities summed across all items in UP. We find that bidders submit 2% lower score in FP than in UP while there are no statistically significant differences in entry, winning score, and the final payment to contractors across the contractual arrangments.

Consistent with the procurement auction literature, we find that most of the variation in score and final payments are explained by the variation in engineers' cost estimates. An additional participating rival bidder is associated with 1% reduction in score, suggesting that competition drives down the price.[19] Bidders becomes less competitive as their own utilization rates increase since a higher level of utilization rate increases the cost of procurement. As the increase in rivals' utilization rate implies that rivals become less competitive, a bidder becomes less competitive as its rivals' utilization rates increase.

describe the nature of the project type.

[19]The strong negative correlation between the score and the number of participating bidders suggests that bidders are competing in private value paradigm rather than common value paradigm.

Table 3: Contract Formats, Bidder Behavior, and Auction Outcomes

Dependent Variable	$entry$	$ln(score)$		$winner's\,ln(score)$		$ln(final\,payment)$	
FP (=0 if UP, =1 if FP)	.00140	-.0214	-.0259	-.00790	-.0156	.00243	-.00531
	(.0035)	(.014)	(.014)	(.015)	(.014)	(.016)	(.016)
log(engineer's cost estimate)	-.00941	.976	.974	.992	.989	1.00	1.00
	(.0018)	(.0056)	(.0056)	(.0063)	(.0063)	(.0067)	(.0066)
# of pariticipating bidders			-.0108		-.0241		-.0241
			(.0028)		(.0030)		(.0032)
# of plan holders	-.000701	.000010	.000717	.000055	.00133	.000194	.00147
	(.00012)	(.00033)	(.00036)	(.00040)	(.00042)	(.00043)	(.00045)
log(district office budget)	-.00174	-.00115	.00540	.0369	.0485	.0341	.0458
	(.0063)	(.028)	(.028)	(.030)	(.030)	(.034)	(.034)
District FE	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes
Month FE	yes	yes	yes	yes	yes	yes	yes
Project Type FE	yes	yes	yes	yes	yes	yes	yes
Bidder FE	yes	yes	yes	yes	yes	yes	yes
R^2	.533	.975	.975	.979	.980	.976	977
N	75714	8977	8977	1888	1888	1888	1888

Clustered standard errors in parentheses. Project types are defined as a linear combinations of tasks, which are extracted from work description of bid tabs. Bidders that have won less than one percent of the total value of projects during the sample period are grouped together as fringe firms, and treated as the same bidder in controlling for bidder fixed effect.

4 Unobserved Project Heterogeneity and Skewed Bidding

The institutional facts indicate that the contract choice is unlikely random, and could confound the effects of contractual arrangements on project outcomes. If FDOT's project managers follow the project guidelines, then bids could be low in FP than UP contracts simply because simple projects are procured via FP, and complex projects via UP. Further, if FP contracts indeed reduce the cost of procurement for simple projects while UP contracts are good for projects with a large project risk, then the effects of FP relative to UP depends on unobserved project heterogeneity: project heterogeneity observed by the bidders and the project managers, but not by the econometrician. We show that the FDOT's project manager's contract choice indeed depends on unobserved project heterogeneity in a way consistent with the FDOT's belief that UP contract works well when the project involves much uncertainty.

UP contract, however, may induce bidders to behave opportunistically through a change in the composition of unit-prices. As UP contract compensates for cost-overruns, bidders have much incentive to bid aggressively in expectation to get compensated through cost-overruns. We show that the composition of unit-price bids exhibits a substantial amount of variation for a given auction, and the unit-price composition is strongly related to bidders' chances of winning.

4.1 Selection on Unobserved Project Heterogeneity

The OLS comparison suggests little differences in project outcomes and bidders' behavior across the two contractual arrangements. The contract choice, however, may not be exogenous. Here, we describe a simple framework to test whether the contract choice depends on unobserved project heterogeneity through the correlation in contract choices and bidding strategies.

Let X be a vector of project and bidder characteristics, and let $Z \supset X$ be a vector of exogenous observables relevant to FDOT's project manager's contract choice, denoted by V. Let $score_f$ and $score_u$ denote the score submitted by a bidder under FP contract and UP contract, respectively. Then, we consider:

$$
\begin{aligned}
V &= Z\gamma + v \\
ln(score_f) &= X\beta_f + \varepsilon_f \\
ln(score_u) &= X\beta_u + \varepsilon_u
\end{aligned}
$$

and FDOT's project manager's choice between FP and UP is governed by:

$$
FP = \begin{cases} 1 & \text{if} \quad V \geq 0 \\ 0 & \text{if} \quad V < 0 \end{cases}
$$

where γ, β_f, and β_u are vectors of parameters. We assume v, ε_f, and ε_u are trivariate normal random unobservables with $Var(\varepsilon_f) \equiv \sigma_f^2$, $Var(\varepsilon_u) \equiv \sigma_u^2$, $Var(v) = 1$, $corr(v, \varepsilon_f) \equiv \rho_f$, and $corr(v, \varepsilon_u) \equiv \rho_u$. The unobservables are assumed to be independent of Z.

The idea of the test is as follows. If project risk is not fully captured by the observables and project managers follow the project guideline, then unobservable v captures unobserved project risk and the project manager is less likely to use FP contract when the project risk is high. We also expect that the unobserved project risk is captured by ε_f as bidders' unobserved costs are likely increasing in unobserved project risk. Thus, the contract choice and bidding strategy in FP is negatively correlated (i.e., $\rho_f < 0$) if project risk is not fully captured by the observables. Similarly, we would expect $\rho_u > 0$ but the correlation may be weak if UP contract is robust to project risk since bidders' unobserved costs are not increasing fast in project risk.

The expected score given a contract format and observables Z is given by:

$$E\left[ln(score_j)|FP=1,\,Z\right] \quad = \quad X\beta_j + \rho_j\sigma_j\frac{\phi(Z\gamma)}{\Phi(Z\gamma)} \tag{1}$$

$$E\left[ln(score_j)|FP=0,\,Z\right] \quad = \quad X\beta_j - \rho_j\sigma_j\frac{\phi(Z\gamma)}{1-\Phi(Z\gamma)} \quad \text{for } j \in \{f,\,u\} \tag{2}$$

where $\phi(.)$ and $\Phi(.)$ are PDF and CDF of a standard normal random variable, respectively. We test $H_0 : \rho_j = 0$ against $H_A : \rho_j \neq 0$ for $j \in \{f, u\}$. As we need some excluded variables in Z that do not enter X to identify ρ_j without relying on identification by functional form assumption, we now turn to the description of our excluded variables.

4.2 Excluded Variable

Our excluded variables capture the backlog level of a district office, measured by the total dollar value of unfinished projects that the district office has at the time of procurement. UP contracts involve a large administrative cost since the FDOT needs much more personnel to keep track of materials used during the construction phase of a project. Therefore, an FDOT's project manager is likely to choose FP contract when the office is heavily backlogged. Since bidders are also likely backlogged when district offices are backlogged, we construct bidder backlog in the same manner and directly control for it. That is, we argue that the level of district office backlog has nothing to do with bidding strategy (e.g., bidders' unobserved costs) conditional on bidders' backlogs. We construct backlog from each of FP and UP contracts as the level of backlog depends on contract format.

4.3 Estimation Results

Table 4 indicates a strong negative correlation between v and ε_f, consistent with the anecdotal evidence. When the project risk is large, project managers are less likely to choose FP contract and bidders' costs tend to be large, which passed onto their scores. Note here that the bias-corrected expected value (1) indicates that FP contracts generate a lower score than UP contract on average with $\rho_f < 0$.

The weak insignificant correlation between v and ε_u is also consistent with the anecdotal evidence that the FDOT believes UP contract is robust to project risk. If UP contract is robust to project risk, then bidders' costs ε_u would be uncorrelated with the project risk since project risk does not translate into bidders' costs. Therefore, the estimation results here are in line with the FDOT's belief that UP contract should be used for a project with a large amount of project risk.[20]

A concern with our approach here is that the excluded variable may be correlated with unobserved project heterogeneity. The violation of exclusion restriction would arise if the FDOT's project managers realize the complexity of projects well before project letting, and therefore FDOT's project managers may coordinate and decide when to procure which project based on the complexity of projects. Ideally, we would like to check if cost-overrun is correlated with our excluded variables. However, we do not observe the actual cost-overrun under FP contract by construction. Thus, we instead test if time overrun is correlated with our excluded variables. Statistically significant correlation between our excluded variables and ex-post auction outcomes would cast a doubt on the validity of our excluded variables. To implement the idea, we regress the difference between log-difference in completion time and expected contract duration on our excluded variables together with exogenous project characteristics. The regression results are presented in Table 5. We test the null hypothesis that the district office backlogs are correlated with time overrun. We fail to reject the null hypothesis at 10% significance level. Therefore, we conclude that there is no evidence that our excluded variables are correlated with project risk.

If UP contract is robust to project risk and generates a lower score than FP contract, then why would the FDOT use FP contract? One reason may be to avoid a high administrative cost of using UP contract. In the following subsection, we show another reason why the FDOT may wish to avoid using UP contract.

[20] The estimation results also suggest that $\sigma_f > \sigma_u$: scores are more dispersed under FP than UP. Our model is also consistent with this observation.

Table 4: Endogenous Switching Model: Estimation Results

Dependent Variable	$ln(score)$	
Regime	FP	UP
ρ_f, ρ_u	-.611	.092
	(.21)	(.11)
σ_f, σ_u	.315	.221
	(.031)	(.010)
District Office Backlog	yes	yes
Bidder Characteristics	yes	yes
Project Characteristics	yes	yes
N	8977	8977

Jackknife clustered standard errors are computed by removing one district-year-month culster at a time. Project characteristics include engineer's estimate of project cost, number of plan holders, project type fixed effects, month fixed effects, year fixed effects, and district fixed effects. Project types are defined as a linear combinations of tasks, which are extracted from work description of bid tabs. Bidder characteristics include bidder backlog from FP and UP contracts, and bidder fixed effects. Bidders that have won less than one percent of the total value of projects during the sample period are grouped together as fringe firms, and treated as the same bidder in controlling for bidder fixed effect. District office backlog is calculated as the total dollar value amount of projects uncompleted at the time of project letting.

Table 5: Test of Endogeneity of Excluded Variable

Dependent Variable	Time Overrun	
F-Test ($p-$value)	0.23	0.41
Bidder Characteristics	no	yes
Project Characteristics	yes	yes
N	1888	1888

Time overrun is defined as log-difference in actual construction days and expected contract days. The null hypothesis for the F-test is the coefficients on polynomial function of excluded variables (district office backlog) are jointly zero.

4.4 Skewed Bidding

Table 6 presents top 10 most frequently used items in UP contracts. It appears that contractual arrangements differ across items. Indeed, some items are procured in lump-sum manner, i.e., there is no adjustment on payment associated with quantity adjustments in these items.[21] Figure 3 shows the dis-

[21] The payment to a contractor for an item on per-day contract would differ based on the actual duration of a project. If a project finishes early, then the payment to a contractor would be lower than its unit-price multiplied by the estimated quantity for that item.

tribution of the sum of unit-prices across lump-sum items as a share of the score submitted by a bidder. It turns out that, on average, a bidder's score derives its 5-45 percent of the value from lump-sum items, and 55-95 percent from non-lump-sum items.

Table 7 shows where the variation in the value of non-lump-sum item comes from by decomposing the variance of share of bids on non-lump-sum item. It reveals that 30% of the total variance comes from within-auction. The question here is why bidders differ so much in the composition of unit-price bids for a given auction.

Table 8 shows regression of score and winning status on the share of bids on non-lump-sum items. It shows bidders with a large share of bids on non-lump-sum items bid much more aggressively than those with a small share. We find that a bidder with one standard deviation higher share of non-lump-sum bids submit a 3.4% lower score, and 7.3% more likely to win a project. The results are based on the specification with only auction fixed effect, and the correlation is even stronger with bidder fixed effect. The results here poses a question as to why bidders with a higher share of non-lump-sum bids have an incentive to bid more aggressively than those without.

One may suspect that more risk-averse bidders would place a larger weight on non-lumpsum item and bid more aggressively than less risk-averse bidders if bidders are characterised by decreasing absolute risk aversion.[22] If this was the case, however, we would observe that inclusion of bidder fixed effects to remove some of the confounding effects rather than strengthening the result.

Figure 4 shows the scatter plot of cost-overrun in UP against winners' bids on non-lump-sum items, which shows a clear positive relationship. We find that cost-overrun is increasing in the bid on non-lump-sum items on average, suggesting that skewing bid is associated with a larger cost-overrun.[23]

[22]This point is made by Phil Hail in Athey and Levin (2001).

[23]One might suspect that the correlation simply captures project size heterogeneity and cost-overrun. From conversation with FDOT's project managers, we confirm that most of the cost overruns actually derives from changes in quantity on contracted items.

Table 6: Contract Type of Top 10 Items in UP contracts

Item Category	**Contractual Arrangement**	**Frequency**
Mobilization	Lump-Sum	1241
Maintenance of Traffic	Lump-Sum	1239
Work Zone Sign	Per Day	1217
Temporary Barricade	Per Day	1168
Advance Warning / Arrow Board	Per Day	890
High Intensity Flashing Lights	Per Day	1200
Temporary Retro-reflective Pavement Marker	Each Unit	865
Portable Changeable Message Sign	Per Day	1004
Clearing & Grubbing	Lump-Sum	1067
Painted Pavement Markings	Lump-Sum	788

The means are calculated using the lowest bidder's unit-price bid from 1341 unit-price auctions. Quantity is estimated by the FDOT prior to auction.

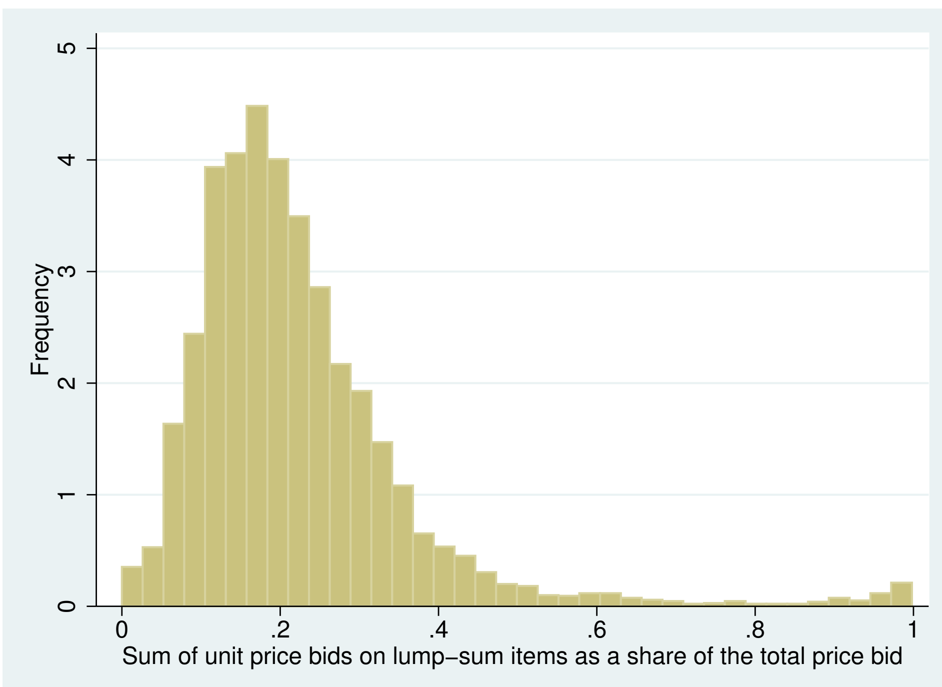

Figure 3: Share of the sum of unit-price bids on lump-sum items in score

Table 7: Variance Decomposition of Share of Non-Lump-Sum Bids

	Std. Dev.	Percentage
Between-Auction	.130	70%
	(.0027)	
Within-Auction Between-Bidder	.0560	30%
	(.0005)	

Standard errors in parentheses

Table 8: Share of Non-Lump-Sum Bid and Bidding Strategy

Dependent Variable	log(score)		win	
Share of Non-Lump-Sum Bid	-.636	-.832	1.35	1.58
	(.030)	(.034)	(.10)	(.11)
Auction FE	Yes	Yes	Yes	Yes
Bidder FE	No	Yes	No	Yes
N	6373	6373	6373	6373

Standard errors in parentheses

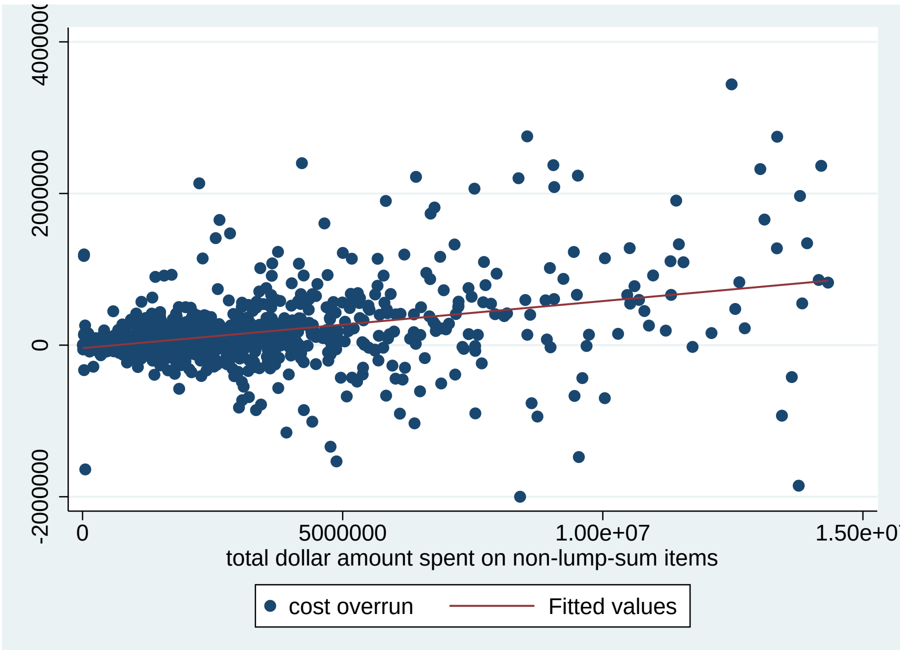

Figure 4: Cost Overrun and Bids on Non-Lump-Sum Items

5 Structural Model

The empirical evidence suggests that i) UP contracts are robust to project risk, ii) scores are more densely distributed in UP than in FP contract, iii) bidders are substantially heterogeneous in the extent of skewed bidding, and iv) bidders skewing their bids towards non-lump-sum items are much more likely to win a project. We construct a structural model of bidding for contracts, consistent with these empirical findings.

UP contract differs from FP contract in that contractors are compensated through cost-overrun on contracted items, and that bidders can hedge against project risk by forming a portfolio of unit-price bids. Since bidders differ in their quantity estimates, the portfolio of unit-price bids also differ: bidders submit high unit-prices for underestimated items while submitting low unit-prices for overestimated items. The bidder with the largest estimate has the largest incentive to win the contract, and therefore bid aggressively in expectation to get compensated through cost overruns. This incentive to skew unit-price bids dissipates with an increase in project risk since skewed bidding comes with an increase in payoff uncertainty.

We extend the model of Ewerhart and Fieseler (2003) in various dimensions to capture empirically relevant features of the environment. First, we introduce multi-dimensional bidder heterogeneities to add flexibility in multidimensional bidding strategies. Without multi-dimensional bidder heterogeneities, multi-dimensional bidding strategies would be a function of a single type, which is restrictive and cannot rationalize the observed distribution of bids in the data. Second, we introduce risk-aversion to account for the fact that complete skewing is not observed in the data. Lastly, we endogenize entry decision of bidders as a change in contract format affects bidders' incentive to participate in an auction. In particular, we will see that UP contract leads to more competition than FP since skewed bidding and risk-hedging raises the expected return from entering in an auction, ceteris paribus.

Our model differs from Bajari et. al. (2013) in that we allow for expected quantity of work items to differ across bidders and bidders face uncertainty in actual quantity of work items. Relaxing these assumptions explains why the composition of unit-price bids varies much in any given auction and also explains why bidders do not completely skew their bids. The timing of events is as follows.

1. **Entry Stage:** Consider N risk-averse potential bidders with a constant absolute risk aversion utility, $u(.)$.[24] Each of N potential bidders independently draws an entry cost, k_i, from a common

[24] CARA assumption may seem restrictive since projects are heterogeneous in project sizes and bidders may be more

distribution $F_{ec}(.)$. Bidders are privately informed about their own entry cost and make entry decision simultaneously. All participating bidders learn the number of actual bidders n upon entry.[25]

2. **Bidding Stage:** A project involves two items: a lump-sum item and a non-lump-sum item.[26] Let θ_1 and θ_2 denote the cost of providing lump-sum and non-lump-sum items at the FDOT's quantity estimates. These costs are common to all participating bidders.[27] Upon entry, bidder i learns its own estimate of quantity, denoted by e_{ij} for item $j \in \{1, 2\}$. The estimate e_{ij} is private information of bidder i, and drawn independently across bidders from a common joint distribution H. The distribution H has a smooth density over a finite positive support. Assume that $\mathrm{E}[e_{ij}] = 1$ and e_{ij} is interpreted as a percentage deviation in quantity estimate from the FDOT's quantity estimate. Given the quantity estimates, all participating bidders simultaneously submit prices b_{ij} on item j. The contractor is selected based on the score $s_i \equiv b_{i1} + b_{i2}$. That is, the bidder with the lowest score wins the project.

3. **Implementaion Stage:** The project manager makes adjustments on non-lump-sum item, denoted by ϵ_2 which is independently drawn from a normal distribution (i.e., $\epsilon_2 \sim N(0, \sigma_2)$).[28] The demand shock affects the quantity required to complete the project.[29] The contractor receives payment based on the contract format.

risk-averse in a larger project. In order to allow for heterogeneity in the level of risk-aversion, we let risk-aversion depend on project size (and project characteristics in general) later in the identification section.

[25]We assume that all the primitives that are common to all potential bidders are common knowledge at the time of entry.

[26] Extending the model to multiple lump-sum items with multiple non-lump-sum items can be done without adding any difficulty in equilibrium characterization, but impose difficulty in estimation. Thus, we describe the simple model which we estimate in the later section.

[27]We assume that there is always more than one bidder enters in any given auction. The assumption that more than one bidders enter is to prevent the unintuitive bidding strategy in which the bidder submits an infinitely high score when it turns out that the bidder is the only one entering the auction. There are only a few auctions with only one participating bidder in the data. This assumption is also adopted in Li and Zheng (2009).

[28]It is possible to allow for correlation between bidders' private information e_{i2} and ex-post shock ϵ_2, but this makes the model significantly more notationally involved and turns out empirically not relevant. Thus, we present the model where ex-post shock is independently distributed of private information e_{i2}.

[29]Since the demand shock on lump-sum item does not affect the characterization of equilibrium bidding strategy and its dispersion is not identifiable, we set $\epsilon_1 = 0$. This abstraction of uncertainty in non-lump-sum item is justified under CARA assumption since bidders would adjust their bids by exactly the risk premium. See Eso and Whilte (2004) for details.

We first consider UP contract. The final payment to the winning bidder, denoted by $p_{u,i}$, is given by:

$$p_{u,i} \quad = \quad b_{i1} + b_{i2}(e_{i2} + \epsilon_2), \tag{3}$$

where there is no uncertainty in payment for lump-sum item. The additive separability in the private information e_{ij} and the demand shock ϵ_2 implies common uncertainty across bidders in the sense that the project risk does not depend on private information e_{ij}.

Note that the final payment to a contractor could differ for two different reasons. First, the final payment may differ from the score s_i due to e_{i2}. For example, suppose that non-lump-sum item is contracted on day basis. That is, b_{i2} specifies how much bidder i receives if it completes the project on the auctioneer's expected completion date. In reality, bidders differ in terms of speed in delivering the project. Some bidders are fast ($e_{i2} < 1$) while others are slow ($e_{i2} > 1$). Thus, the payment scheme implies that fast contractors receive a lower amount of payment than slow contractors, ceteris paribus. Second, the final payment may differ from the score s_i due to demand shock ϵ_2. Bidders' estimates are also imperfect, and affected by unexpected change in the project plan. The demand shock ϵ_2 captures unexpected delay in project implementation, and $\text{Var}\,(\epsilon_2) \equiv \sigma_2$ captures project risk.

The total cost of implementing the project, $tc_{u,i}$, is defined as:

$$tc_{u,i} \quad = \quad \theta_1 e_{i1} + \theta_2(e_{i2} + \epsilon_2), \tag{4}$$

Bidder i's interim expected payoff upon entry, $\pi_{u,i}$, is defined as:

$$\pi_{u,i} \quad = \quad \max_{b_{i1},b_{i2}} \int E\left[u\left(p_{u,i} - tc_{u,i}\right)|\boldsymbol{\mathcal{I}}\right] \boldsymbol{dF_{tc,-i}}, \tag{5}$$

where $\boldsymbol{\mathcal{I}} \equiv \{\theta_1, \theta_2, \alpha, \sigma_2, e_{i1}, e_{i2}, \boldsymbol{F_{tc}}, n\}$, E[.$|\boldsymbol{\mathcal{I}}$] is the expectation over the distribution of ϵ_2, and $\boldsymbol{F_{tc,-i}}$ is the distribution of rivals' types.

Given the normal distribution assumption on ϵ_2 and CARA utility, the inner problem of a bidder can be written as:

$$\max_{b_{ij}\geq 0} \; b_{i1} + b_{i2}e_{i2} - (\theta_1 e_{i1} + \theta_2 e_{i2}) - \frac{\alpha\sigma_2}{2}(b_{i2} - \theta_2)^2$$
$$s.t. \; s_i = b_{i1} + b_{i2},$$

where $\alpha > 0$ is the CARA risk-aversion coefficient. Solving this simple constrained optimization problem gives:

$$b_{i2}^* = \begin{cases} s_i & \text{if } e_{i2} - 1 \geq \alpha\sigma_2(s_i - \theta_2) \\ 0 & \text{if } e_{i2} - 1 \leq -\alpha\sigma_2\theta_2 \\ \theta_2 + \frac{1}{\alpha\sigma_2}(e_{i2} - 1) & \text{otherwise} \end{cases} \tag{6}$$

Proof in Appendix. The condition (6) shows some interesting relationship between project risk σ_2 and bid skewness. For example, consider the case of no project risk, $\sigma_2 = 0$. Those bidders with a large cost of delivering non-lump-sum item (i.e., $e_{i2} > 1$) skew their bid toward non-lump-sum item completely, and submit $\{b_{i1}^* = 0, b_{i2}^* = s_i\}$. On the other hand, those bidders with a small cost of delivering non-lump-sum item (i.e., $e_{i2} < 1$) skew their bid toward lump-sum item completely, and submit $\{b_{i1}^* = s_i, b_{i2}^* = 0\}$. Now, consider the other extreme case in which $\sigma_2 = \infty$. The optimal bidding strategy of a bidder of any type e_{i2} is $\{b_{i1}^* = s_i - \theta_2, b_{i2}^* = \theta_2\}$. Thus, the incentive to skew bids goes away as the project risk increases.

For the rest of the paper, we consider the case of moderate project risk in which the solution to the inner problem above is $b_{i2}^* = \theta_2 + \frac{1}{\alpha\sigma_2}(e_{i2} - 1)$ since we do not observe in the data either complete skewed bidding or auctions with the same bid amount submitted on non-lump-sum items.

Note that b_{i2}^* is increasing in e_{i2}, which implies that a high cost bidder that uses many non-lump-sum items bid high on non-lump-sum items. For example, if a non-lump-sum item is contracted on day basis, then a slow bidder will bid high on those non-lump-sum items.

Given b_{i2}^*, we have $b_{i1}^* = s_i - \left(\theta_2 + \frac{1}{\alpha\sigma_2}(e_{i2} - 1)\right)$ and so the bidder's problem reduces to one-dimensional choice problem, such that:

$$\pi_{u,i} = \max_{s_i} \int u(s_i - c_{u,i}) \boldsymbol{dF_{u,-i}}, \tag{7}$$

where $c_{u,i}$ is the pseudo-type of the bidder i defined as:

$$c_{u,i} \equiv \theta_1 e_{i1} + \theta_2 - \frac{1}{2\alpha\sigma_2}(e_{i2} - 1)^2. \tag{8}$$

and $\boldsymbol{dF_{u,-i}}$ is the distribution of rivals' pseudo-types. Note here that $c_{u,i}$ is inverse U-shaped in e_{i2}, which implies that the score s_i is non-monotone in e_{i2} in a monotone equilibrium in which s_i is non-decreasing in $c_{u,i}$. This means that those whose estimate on the non-lump-sum items differ substantially from the auctioneer's estimate would bid more aggressively than those whose estimates are close to the auctioneer's estimate. In the example of fast and slow bidders, the model implies that slow bidders bid more aggressively than moderately fast bidders that can deliver the project on the auctioneer's expected completion date. Slow bidders know that the project will be delayed if they win the contract. Thus, slow bidders skew their bids towards non-lump-sum item, and lower its score in expectation to get compensated by ex-post adjustment on non-lump-sum items.

Since the rest of the equilibrium characterization is already done in the auction literature, we summarize the rest in the following proposition.

Proposition 1. *The unique symmetric, monotone, and differentiable equilibrium bidding strategy is characterized by the following differential equation and the initial condition:*

$$\begin{aligned} \frac{\partial s(c_u;n)}{\partial c_u} &= 1 + \frac{(n-1)f_u(c_u)}{\alpha(1-F_u(c_u))}\left(\exp\left\{\alpha(s(c_u;n)-c_u)\right\} - 1\right) \\ s(\bar{c}_u;n) &= \bar{c}_u, \end{aligned} \tag{9}$$

where F_u and f_u are CDF and PDF of c_u, which is continuous and bounded over $[\underline{c}_u, \bar{c}_u]$.

Given the unique bidding strategy above, a potential bidder decides to enter in an auction if the expected profit from entering is greater than the cost of entry. As shown in Krasnoktsukaya and Seim (2011), the unique symmetric equilibrium entry strategy is given by the entry threshold utility $\bar{u}$, which is determined by:

$$\sum_{n}^{N} \binom{N-1}{n-1} \delta(\bar{u}(N))^{n-1}(1-\delta(\bar{u}(N)))^{N-n} \int u\left(s(c_u;n) - c_u\right) \boldsymbol{dF_{u,n}} = \bar{u}(N) \tag{10}$$

where the left hand side of (10) is the equilibrium expected profit from entering an auction, and $\boldsymbol{F_{u,n}}$ *is the distributions of* c_u *over all* n *entering bidders. The equilibrium entry probability is determined by* $\delta(\bar{u}(N)) \equiv \Pr(u(-k) < \bar{u}(N))$. *That is, a bidder participates in an auction if the bidder's entry cost* k *is below some threshold level which corresponds to the level of utility* $\bar{u}(N)$.

Now, consider the case of FP. The payment, $p_{f,i}$, in FP is given by:

$$p_{f,i} \quad = \quad s_i \tag{11}$$

where s_i is the score of bidder i in FP. That is, the payment in FP is simply the score submitted by bidder i. Therefore, the interim expected payoff of bidder i in FP with CARA utility is given by:

$$\pi_{f,i} \quad \equiv \quad \max_{s_i} \int u\left(s_i - c_{f,i}\right) \boldsymbol{dF_{f,-i}} \tag{12}$$

where the pseudo-type of bidder i, $c_{f,i} \in [\underline{c}_f, \bar{c}_f]$, is defined as:

$$c_{f,i} \equiv \theta_1 e_{i1} + \theta_2 e_{i2} + \frac{\alpha\sigma_2}{2}\theta_2^2. \tag{13}$$

The distributions of the pseudo-types for opponents is denoted by $\boldsymbol{F_{f,-i}}$. Equilibrium characterization of FP follows exactly the same steps.

The pseudo-types from UP and FP show that bidders' cost structure endogenously change with respect to contractual arrangements. In particular, the cost of project risk is increasing slower in UP than FP. Thus, we expect that UP performs better than FP for a project with a large project risk. On the other hand, UP may suffer from selecting an inefficient contractor who has a large incentive to get compensated through cost-overruns.

5.1 Bidding Strategies and Contract Outcomes

We demonstrate the effect of contract formats on the distribution of pseudo-types and the expected final payment under varying levels of project risks. The distribution of pseudo-types in Figure 5 shows that i) pseudo-cost increases faster under FP than UP in project risk, and ii) the distribution of pseudo-types under UP contract is more densely distributed than FP and shows relatively lower costs when project risk is large. These differences in peudo-costs are directly translated into the distribution of scores. Figure 6 plots the expected final payment against project risk. The expected final payment is lower under FP than UP when project risk is low while the expected final payment is low under UP than FP when project risk is high.

The intuition of the results is best explained with an example. Suppose that the pay scheme for the non-lump-sum item in UP is based on days required to complete the project. Those firms that deliver the project fast will be paid less than those slow firms, ceteris paribus. Therefore, slow firms have a larger incentive to win the contract in expectation to get compensated through larger cost overruns than fast firms. This leads to a selection of a slow contractor with large cost overruns because bidders that bid aggressively are the ones that expect and involve large cost overruns. Since there is a trade-off between risk-hedging and skewed bidding, the incentive to skew bids decreases in project risk. Therefore, FP generates a lower final payment than UP when project risk is low since FP selects an efficient contractor and the cost of project risk is low while UP performs better than FP when project risk is large since UP allows bidders to hedge against project risk and the incentive to skew decreases in project risk.

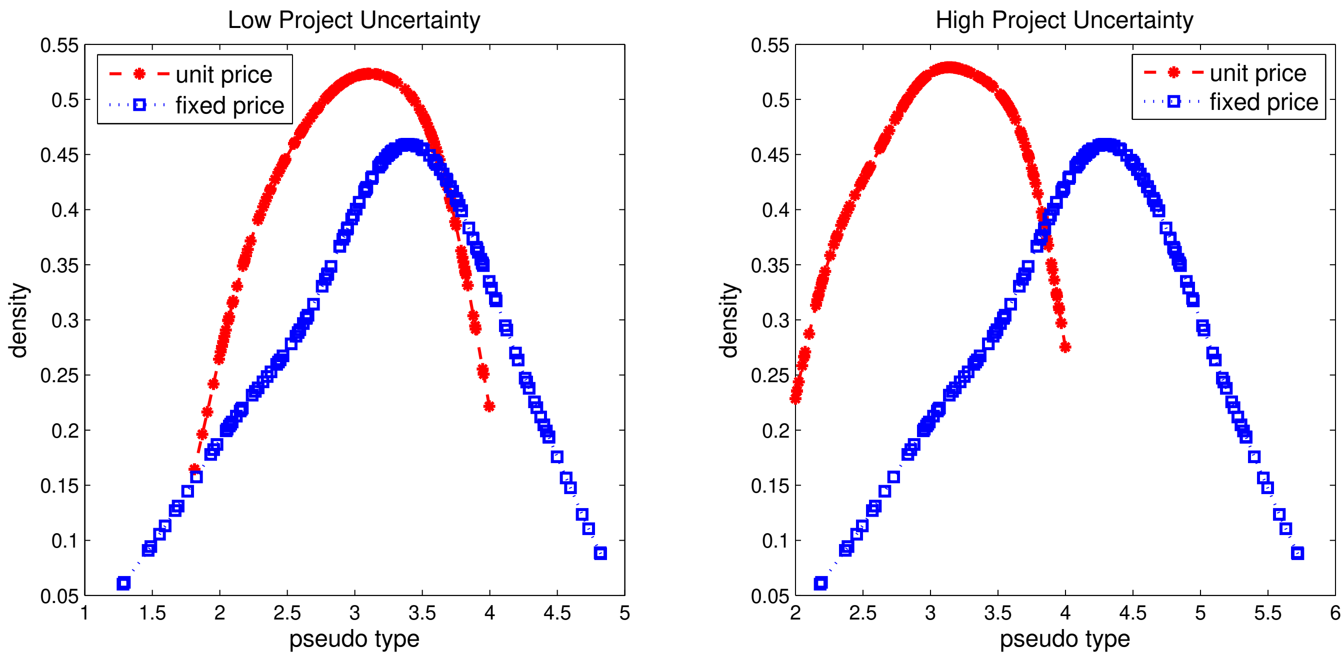

Figure 5: Distributions of Pseudo Cost Types under UP and FP Contracts

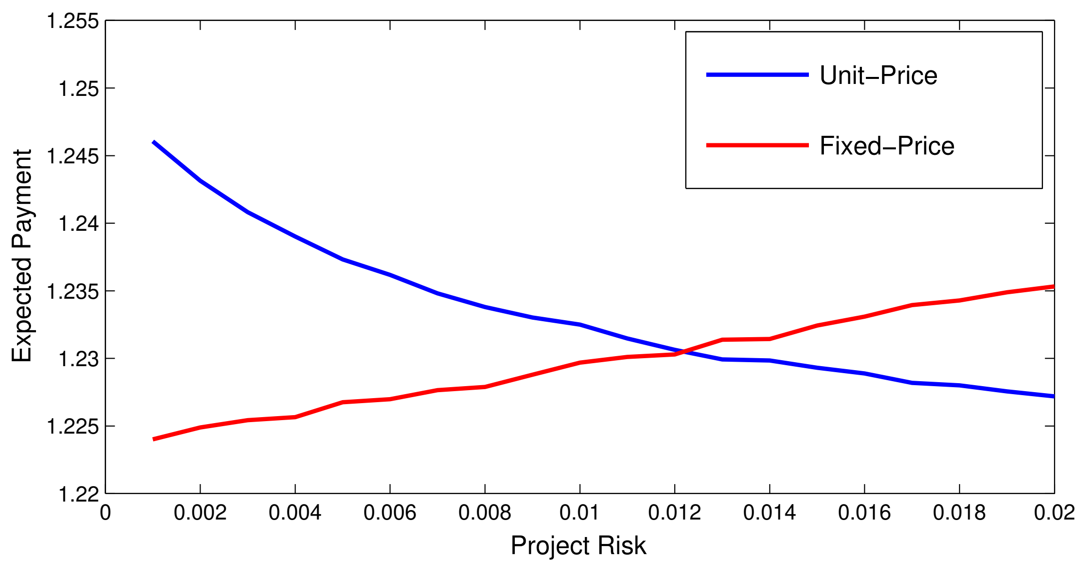

Figure 6: Expected Final Payment and Project Risk in FP and UP Contracts

6 Identification

This section specifies the information structure, the set of model primitives to be identified, and the set of observables used to identify the model primitives. Then, we show that the model is semiparametrically identified.

6.1 Observables, primitives, and information structure

Let X denote a vector of exogenous project characteristics and let $W \subset X$ denote exogenous variables that affect bidding strategy but not entry decision. The econometrician observes the number of potential bidders N, the number of actual participating bidders n, bids on lump-sum and non-lump-sum items for all participating bidders, $\{b_{i1}, b_{i2}\}_{i=1}^{n}$, and cost overruns on contracted items Δ_2 in UP contracts. Without loss of generality, we rank bidders based on the score $s_{u,i} = b_{i1} + b_{i2}$, and refer to the winner of an auction by 1.

The primitives to be identified are the joint distribution of bidders' types H, common cost components $\theta_j(X)$ for $j \in \{1, 2\}$, risk-aversion parameter $\alpha(X)$, project risk $\sigma_2(X)$, and the distribution of entry cost, F_{ec}. Let $\mathcal{I}_i$ denote bidder i's state at the time of bidding. Identifying Assumption 1 summarizes what bidders know at the time of bidding.

Identifying Assumption 1. *The state of bidder i at the time of bidding $\mathcal{I}_i$ consists of auction heterogeneities, bidder i's private information, the joint distribution of rival bidders' private information, the number of participating bidders, procurar's estimated costs, project risk, and the number of actual bidders:* $\mathcal{I}_i \equiv \{\theta_1(X), \theta_2(X), \alpha(X), \sigma_2(X), e_{i1}, e_{i2}, \boldsymbol{H}, n\}$.

Identifying Assumption 1 is standard in the empirical auction literature. The assumption that the number of actual bidders is a common knowledge can be tested. We find that scoring strategy of bidders is strongly negatively correlated with the number of actual bidders, suggesting that firms know how many rivals they face at the time of bidding and bid more aggressively as the number of participating bidders increases.

Identifying Assumption 2. *Bidders' private information is i.i.d. across bidders and also independently distributed from entry cost conditional on project characteristics. That is, the bid preparation cost is irrelevant of its productivity conditional on project characteristics.*

Identifying Assumption 2 is required for the identification of the distribution of bidders' private types H. Intuitively, the econometrician has no way of detecting which one of bidders' private information, e_{i1} or e_{i2}, is correlated with its entry cost from the data, precluding the possibility to allow for selection on entry cost.

Identifying Assumption 3. *Ex-post adjustments on non-lump-sum bids ϵ_2 is independently distributed from non-lump-sum bid b_{12}.*

Identifying Assumption 3 abstracts from the possibility that FDOT's project managers reduce (resp. increase) the demand for ex-post adjustments in case the non-lump-sum bid submitted by the contractor is high (resp. low), resulting in endogenous demand for adjustments. We argue that ex-post adjustment is exogenous in this context based on two grounds. First, it will jeopardizes the point of using UP contract if the FDOT does not commit. Bidders will adjust their belief about the distribution of ex-post adjustments.[30] Second, construction items and tasks are typically non-storable and the FDOT has little incentive to purchase non-lump-sum items when they are cheap and store for later use.

Identifying Assumption 4. *There is at least one variable $W \subset X$ that affects the cost of implementing a project but does not affect entry cost.*

Identifying Assumption 4 is required for the identification of entry cost distribution. Without a variable W, all we can identify is the probability of entry and any distribution of entry cost can be rationalized by the data.[31] To this end, we assume that bid preparation cost is independent of project size conditional on project type.

6.2 Semiparametric identification

We show that the model primitives are identified from the data on UP contracts and do not rely on the variation in the use of contract formats.

[30]Based on private conversation with FDOT's project managers, we confirm this is indeed the concern that the FDOT has.

[31] See online appendix of Krasnoktsukaya and Seim (2011) for details.

Proposition 2. *Under Identifying Assumption 1-4, all the model primitives are identified.*

First, consider the non-lump-sum bidding strategy given in (6). It is straightforward to see that $\theta_2(X)$ is directly identified from the equation (6), such that:

$$\mathrm{E}\left[b_{i2}|X\right] \;=\; \theta_2(X). \tag{14}$$

since $\mathrm{E}[e_{ij}] = 1$. Given the knowledge about $\theta_2(X)$, we identify $\alpha(X)$ and $\sigma_2(X)$ from the mean and the variance of cost-overruns. Note here that the cost-overrun is defined as $\Delta_2 \equiv b_{12}(e_{12} + \epsilon_2)$. Substituting the non-lump-sum bidding strategy given in (6) into the cost-overrun gives:

$$\begin{aligned}\frac{\Delta_2}{b_{12}} &= e_{12} - 1 + \epsilon_2 & (15)\\ &= \alpha(X)\sigma_2(X)(b_{12} - \theta_2(X)) + \epsilon_2 & (16)\end{aligned}$$

where the second equality follows from the first order inversion with respect to b_{12}. Therefore, the extent risk-aversion $\alpha(X)$ and project risk $\sigma_2(X)$ is identified from the mean and the variance of cost-overruns conditional on b_{12}, such that:

$$\begin{aligned}\mathrm{E}\left[\frac{\Delta_2}{b_{12}}|b_{12}, X\right] &= \mathrm{E}\left[\alpha(X)\sigma_2(X)(b_{12} - \theta_2(X)) + \epsilon_2|b_{12}, X\right] & (17)\\ &= \alpha(X)\sigma_2(X)(b_{12} - \theta_2(X)) & (18)\\ \mathrm{Var}\left[\frac{\Delta_2}{b_{12}}|b_{12}, X\right] &= \mathrm{Var}\left[\alpha(X)\sigma_2(X)(b_{12} - \theta_2(X)) + \epsilon_2|b_{12}, X\right] & (19)\\ &= \sigma_2(X). & (20)\end{aligned}$$

Given the knowledge about $\alpha(X)$, $\sigma_2(X)$, and $\theta_2(X)$, we can now identify the distribution of e_{i2} nonparametrically from:

$$\alpha(X)\sigma_2(X)(b_{i2} - \theta_2(X)) \;=\; e_{i2}$$

Now, let $G_n(.|X)$ and $g_n(.|X)$ denote the CDF and PDF of score distributions with n participating bidders conditional on observables X. Expressing the first order optimality condition (9) in terms of bid distributions gives:

$$\text{E}\left[s_{u,i} - \theta_2(X) - \frac{1}{\alpha(X)} ln\left(1 + \alpha(X)\frac{1 - G_n(s_{u,i}|X)}{(n-1)g_n(s_{u,i}|X)}\right) + \frac{1}{2}\alpha(X)\sigma_2(X)(b_{i2} - \theta_2(X))^2|b_{i2}, X\right] = \theta_1(X). (21)$$

See Appendix for the derivation of (21). Thus, we identify $\theta_1(X)$. Given $\theta_1(X)$, we can identify H_1 from:

$$\left[s_{u,i} - \theta_2(X) - \frac{1}{\alpha(X)} ln\left(1 + \alpha(X)\frac{(1 - G_n(s_{u,i}|X))}{(n-1)g_n(s_{u,i}|X)}\right) + \frac{1}{2}\alpha(X)\sigma_2(X)(b_{i2} - \theta_2(X))^2\right]/\theta_1(X) = e_{i1}. (22)$$

Lastly, the entry cost k is identified from the equilibrium entry condition given by equation (10). As we know $\theta_j(X)$ and H_j for $j \in \{1, 2\}$, we know the distribution of the pseudo-type F_u, and also the interim expected payoff, $\int u\left(s_u - c_u\right) \boldsymbol{dF_{u,n}}$, for each number of participating bidders n. In order to identify the distribution of entry costs, we need an additional identifying assumption. In particular, we need a variable that affects the expected payoff of bidders but is not related to the entry cost.[32]

7 Structural Estimation

Nonparametric estimation of the model here places a burden on the small sample and suffers from curse of dimensionality. Further, the model is highly nonlinear due to CARA utility assumption. Applied works in the procurement auction literature often assume constant relative risk aversion (CRRA) rather than CARA utility because of its simplicity and goodness of fit to the data. We assume CARA utility because we would need to approximate certainty equivalent payoff via Taylor expansion otherwise, which is valid only for small ex-post adjustments. Since we are aware that the data contain a large degree of ex-post uncertainty, we assume CARA utility together with normally distributed ex-post adjustments.

On top of the nonlinearity caused by CARA assumption, our reduced-form evidence suggests existence of unobserved project heterogeneity. Therefore, the econometrician needs to address the possibility that the extent of project risk may differ across projects in a way unobserved to the econometrician.

We address the above issues by imposing a certain econometric specification and estimate a finite mixture model that allows for a finite number of discrete unobserved states in project risk σ_2 and the

[32]Without this exclusion restriction, we can only identify entry probabilities which can be rationalized by any continuous distribution of entry costs. See online appendix in Krasnoktsukaya and Seim (2011) for details.

mean cost estimates θ_j. Our econometric specification of the model can be interpreted as bidders exhibiting "decreasing absolute risk aversion across projects". In particular, our specification captures the intuition that bidders care less about project risk as project size becomes large. Our econometric specification also suggests an easy-to-estimate multi-step estimation procedure, which allows for estimation of the model primitives together with the distribution of unobserved project heterogeneity via indirect inference. To avoid cluttering, we omit the bidder subscript i from here on.

7.1 Econometric Specification

We specify the model in a single-index framework. More specifically, we rescale all the model primitives by observables X. Let superscript t denote the unobserved (to the econometrician) state. Define:

$$\begin{aligned} \theta_j^t(X) &= \theta_j^t \exp\{X\beta\} \\ \sigma_2^t(X) &= \sigma_2^t \\ \alpha(X) &= \alpha / \exp\{X\beta\} \end{aligned} \tag{23}$$

where superscript t denotes the state of the world. That is, the mean cost estimate and project risk are both allowed to differ across projects in a way that is unobserved to the econometrician. Rescaling of wealth in CARA utility requires normalization of CARA coefficient by $\exp\{X\beta\}$.[33]

One implication of the above econometric specification on the equilibrium bidding strategy is that the scoring strategy, non-lump-sum bidding strategy, and cost-overrun are all multiplicatively separable in observables. To see this, let us make explicit the dependency of outcome variables on the primitives. Let $b_2 \equiv b_2(\theta_2(X), \sigma_2(X), \alpha(X), e_2)$, $s_u \equiv s_u(\theta_1(X), \theta_2(X), \sigma_2(X), \alpha(X), e_1, e_2)$, and $\Delta_2 \equiv \Delta_2(\theta_2(X), \sigma_2(X), \alpha(X), e_2, \epsilon_2)$. Define $b_2^0 \equiv b_2(\theta_2(0), \sigma_2(0), \alpha(0), e_2)$, $s_u^0 \equiv s_u(\theta_1(0), \theta_2(0), \sigma_2(0), \alpha(0), e_1, e_2, n)$, and $\Delta_2^0 \equiv \Delta_2(\theta_2(0), \sigma_2(0), \alpha(0), e_2, \epsilon_2)$ as "normalized" non-lump-sum score, normalized score, normalized cost-overrun, respectively. This multiplicative separability of project characteristics allows bid-homogenization approach in the setting with CARA bidders, and reduces the computational burden by reducing the number of auctions the econometrician has to solve.

[33]See Theorem 1 in Raskin and Cochran (1986) for this.

Proposition 3. *Given the econometric specification above, the unique equilibrium non-lump-sum bidding strategy, scoring stratetgy, and cost-overrun are all multiplicatively separable in project characteristics, such that:*

$$
\begin{aligned}
b_2 &= b_2^0 \exp\{X\beta\} \\
s_u &= s_u^0 \exp\{X\beta\} \\
\Delta_2 &= \Delta_2^0 \exp\{X\beta\}.
\end{aligned}
$$

Proof in Appendix. The econometric specification also has an intuitive property that bidders care less about project risk as the project size gets large. Suppose, for example, that there are two projects/auctions of different sizes with the same level of project risk. If the econometrician assumes that bidders participating in these two auctions have the same CARA coefficient (i.e., constant α), then it means that bidders care about the project risk exactly the same way across the two projects. However, one would imagine that those bidders participating in the auction for a large project care less about the project risk since the level of the project risk is small relative to the markup those bidders make in the large auction compared to the small auction. The above specification that normalizes CARA coefficient by project characteristics incorporates this intuition, and bidders care less about project risk as the project size becomes larger.

7.2 Estimation Steps

Step 1: Partial out the impact of project characteristics on the scoring strategy by running a log-regression of score s_u on the project characteristics.

$$
\ln s_u = X\beta + \ln s_u^0
$$

Step 2: Estimate CARA parameter α, the distribution of unobserved mean cost estimate for non-lump-sum item θ_2^t, the distribution of unobserved project risk σ_2^t, and the marginal distribution of e_2, by maximum likelihood using the following equations on the non-lump-sum bidding strategy and cost-overrun.

$$\begin{aligned} b_2^0 &= \theta_2^t + \frac{e_2 - 1}{\alpha \sigma_2^t} \\ \frac{\Delta_2^0}{b_2^0} &= \alpha \sigma_2^t (b_2^0 - \theta_2^t) + \epsilon_2 \end{aligned}$$

Step 3: Given the estimates obtained from step 1 and 2, estimate the distribution of the cost of lump-sum item by indirect inference following Li (2010). To this end, we match the moments of the score distribution in the data and the moments of score generated via simulation. More specifically, we:

1. Guess the parameters of the distribution of the cost of lump-sum item. Simulate the equilibrium scoring strategy for each actual bidder in the data using the parameter estimates obtained from the earlier steps and the guessed parameters.

2. Compute the moments of the simulated scores conditional on the number of participating bidders.

3. Repeat 1-2 many times and compute the average moments. Search for the parameter values of the cost of lump-sum item by matching the moments generated via simulation and the moments given by the data.

Step 4: Given the parameter estimates obtained from step 1-3 and following the procedure analogous to step3, estimate the distribution of entry costs by matching the moments of the entry distribution in the data and the moments of entry decisions generated via simulation.

7.3 Estimation Results

Finite mixture model requires a priori knowledge about the number of unobserved states. To this end, we conduct an elbow test based on the mean and variance of (normalized) non-lump-sum bids, b_2^0. More specifically, we apply K-means clustering on the mean and variance of b_2^0 for each number of potential clusters, and determine the number of clusters where the sum of squared errors stops dropping radically. The results of the elbow test are presented in Figure 7 and 8. The data seem to contain two unobserved states in both mean and variance of b_2^0. We interpret this as a suggestive evidence that the data contain two unobserved states in the mean cost of lump-sum θ_1^t, non-lump-sum items θ_2^t, and the extent of project risk σ_2^t.

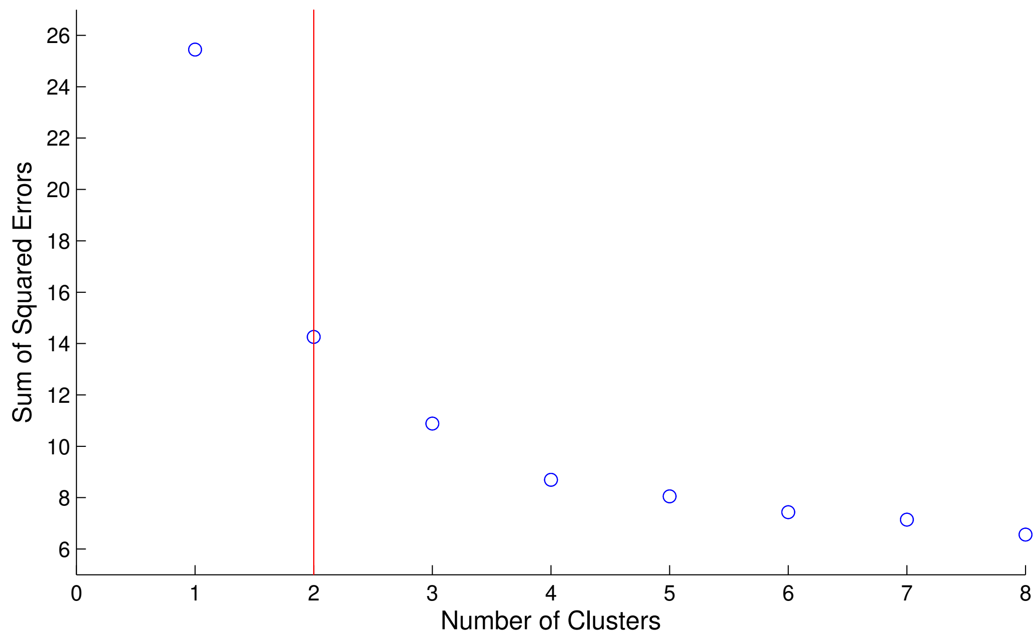

Figure 7: Elbow Test on The Mean of Nonlumpsum Bids

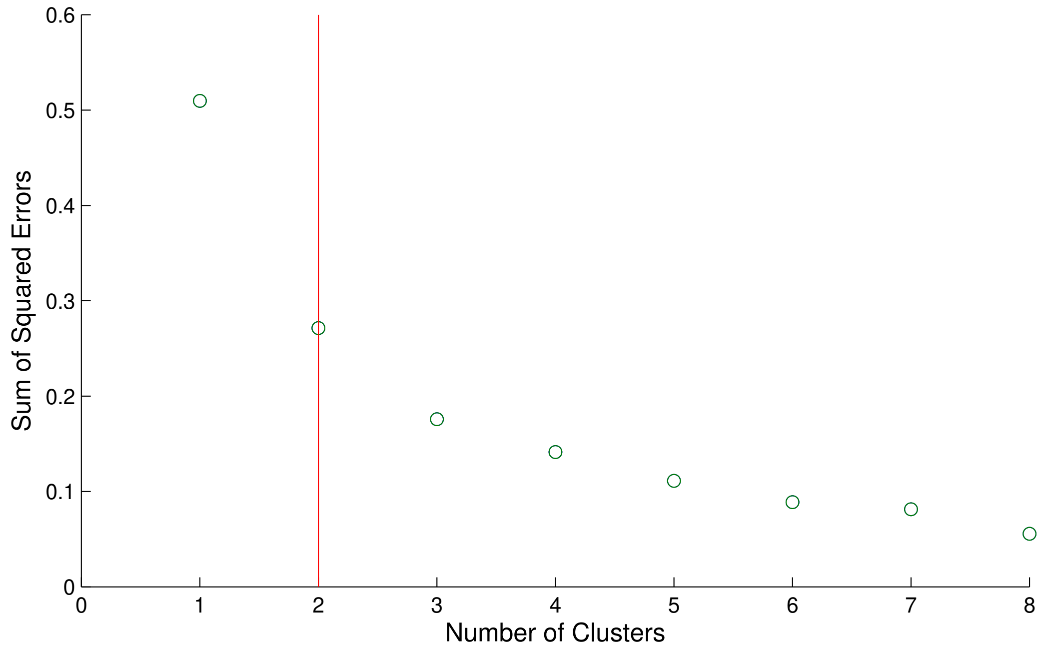

Figure 8: Elbow Test on The Variance of Nonlumpsum Bids

We parameterize the distribution of bidders' types by bivariate normal: $[e_1, e_2] \sim \boldsymbol{N(1, \Sigma)}$ with correlation $\rho \equiv corr(e_1, e_2)$ to allow for within-bidder correlation in types.[34] There are four unobserved states (i.e., all possible combinations of θ_2^t and σ_2^t for $t \in \{L, H\}$) and the distribution of each state occuring is denoted by $\Pr_j$ for $j \in \{LL, LH, HL, HH\}$ where $\Pr_{HH} = 1 - \Pr_{LL} - \Pr_{LH} - \Pr_{HL}$.

As shown in Krasnotsukaya and Seim (2011), we need some exclusion restriction for the identification of entry cost distribution.[35] To this end, we assume that entry costs (or equivalently, bid preparation costs) are independent of engineers' estimates of project cost, which serves as a proxy for a project size, conditional on project types. In order to determine which project type is relevant to entry cost, we regress the number of participating bidders on a linear combinations work description together with engineers' cost estimates. We find that projects that involve at least one of "milling" or "guardrail" are associated with lower rate of entry. We define a project that involves at least one of these tasks as a "minor" project and estimate the distribution of entry costs for minor and non-minor project.

[34] We truncate the top and bottom 1% of the distribution.

[35] Without such exclusion restriction, the econometrician can only recover the probability of entry, which can be rationalized by any entry cost distribution.

Table 9 shows the estimation results. CARA parameter is precisely estimated and largely in line with the estimates found in the literature. There is a large amount of unobserved heterogeneity in both mean cost estimates θ_j^t and project risk σ_2^t. An important observation here is that the bidders' types are highly positively correlated (i.e., $\rho = 0.5$). The finding here has an important implication for the effect of using UP over FP. Since those efficient bidders whose estimate e_2 lower than θ_2 also bids aggressively, if bidders' types (e_1 and e_2) are highly correlated, winning bidders tend to be a bidder with low e_2. Therefore, we expect that an increase in ρ is associated with an increase in allocative efficiency. That is, the adverse effect of using UP over FP contract, which arises from skewed bidding, diminishes with an increase in ρ, and so the use of UP contract can be justified even when the level of project risk is small.

Table 9: Structural Estimation Results

Parameter	α	σ_2^L	θ_1^L	θ_2^L	σ_2^H	θ_1^H	θ_2^H	σ_{e1}	σ_{e2}	ρ
Estimate	.716	0531	.232	1.18	.109	.421	1.53	1.56	.0134	.510
Standard Error	(.13)	(.0031)	(.022)	(.055)	(.0032)	(.049)	(.054)	(.43)	(.0011)	(.098)

Parameter	μ_{ec}^1	σ_{ec}^1	μ_{ec}^2	σ_{ec}^2	$\Pr_{LL}$	$\Pr_{LH}$	$\Pr_{HL}$
Estimate	.101	.012	.145	.013	.341	.211	.0564
Standard Error	(.034)	(.0042)	(.040)	(.0033)	(.017)	(.019)	(.010)

Block-bootstrapped standard errors are presentend in parentheses. Auction level characteristics include the engineer's estimate of project cost and project type. The engineer's cost estimate is an estimate of winning price predicted by an FDOT engineer prior to an auction. Project type is assigned to each project based on project description on bid tabs.

8 How to minimize procurement costs?

A natural question here is whether UP contract is a mechanism that minimizes the cost of procurement. In this section, we consider two hypothetical scenarios: i) switching from UP to FP contract, and ii) imposing a cap on non-lump-sum bids. FP contract is an obvious alternative to UP contract especially when the level of project risk is relatively small. We show that switching to FP contract increases the expected finaly payment to a contractor even when the project risk is small, rationalizing the use of UP contract by the FDOT for those projects in the data.

We consider imposing a cap r on non-lumpsum bid (or equivalently, reserve price) at the estimated mean cost of non-lumpsum item θ_2^t. This experiment will allow us to see how the performance of UP contract can be improved in a simple and costless manner.[36] The intuition is simple but differs in its role from the reserve price in a typical first-price auction. A cap on the non-lumpsum bid at θ_2^t precludes skewing of inefficient types ($e_2 \geq 1$) while allowing for efficient types ($e_2 < 1$) to skew their bids. Since cost-overruns occur due to skewing of inefficient bidders, setting a cap $r = \theta_2^t$ reduces the extent of overrun for inefficient types, which in turn limits the incentive to submit score aggressively, resulting in efficient selection of a contractor via UP contract. More specifically, a bidders' non-lumpsum bidding strategy under reserve price r is given by:

$$b_2 = \begin{cases} \theta_2^t + \frac{e_2 - 1}{\alpha\sigma} & \text{if } e_2 < 1 \\ \theta_2^t & \text{if } e_2 \geq 1 \end{cases}$$

and pseudo-cost of a bidder, c_r, is given by:

$$c_r = \begin{cases} \theta_1^t e_1 + \theta_2^t - \frac{(e_2 - 1)^2}{2\alpha\sigma} & \text{if } e_2 < 1 \\ \theta_1^t e_1 + \theta_2^t & \text{if } e_2 \geq 1 \end{cases}$$

and the scoring strategy is a function of c_r where c_u in equation (9) is replaced by c_r.

Table 10 presents the percentage change in the expected final payment by switching contract formats. We find that switching from UP to FP contract would increase the expected procurement cost in all cases, rationalizing the use of UP contract by the FDOT. We also find that the cost saving effect of UP contract is larger when the project risk is large, and the cost of project risk is large when the mean estimated cost of non-lump-sum item θ_2^t is large.

Table 11 shows the effect of non-lump-sum reserve price on the expected finaly payment. We find that the effect of reserve price is surprisingly small at first glance. This can be explained by two reasons. First, since within-bidder type is highly positively correlated, those bidders that win a contract tend to be efficient (i.e., low e_1 and low e_2) and thus, additional benefit from imposing a reserve price is small. Second, the scope of skewing is limited by the large project risk. A large amount of project risk shifts the

[36] Item-wise reserve price is a very common practice in timber auctions, which also use UP to select a contractor. See Athey and Levin (2001) for example.

attention of bidders from skewing to risk-hedging and therefore, leaving little difference between efficient and inefficient bidders in terms of non-lump-sum bids.

Table 10: Effect of switching from UP to FP on final payment

	State LL (θ_1^L, θ_2^L, σ_2^L)	State LH (θ_1^L, θ_2^L, σ_2^H)	State HL (θ_1^H, θ_2^H, σ_2^L)	State HH (θ_1^H, θ_2^H, σ_2^H)
Change in final payment	2.78%	5.17%	3.27%	6.89%

$\theta_1^L = .232$, $\theta_2^L = 1.18$, $\sigma_2^L = .0531$, $\theta_1^H = .421$, $\theta_2^H = 1.53$, $\sigma_2^H = .109$.

Table 11: Effect of reserve price on final payment in UP

	State LL (θ_1^L, θ_2^L, σ_2^L)	State LH (θ_1^L, θ_2^L, σ_2^H)	State HL (θ_1^H, θ_2^H, σ_2^L)	State HH (θ_1^H, θ_2^H, σ_2^H)
Change in final payment	-0.17%	-0.06%	-0.13%	-0.06%

$\theta_1^L = .232$, $\theta_2^L = 1.18$, $\sigma_2^L = .0531$, $\theta_1^H = .421$, $\theta_2^H = 1.53$, $\sigma_2^H = .109$. Reserve price on non-lumpsum bid is set at θ_2^t.

9 Conclusion

We have studied the performance of UP contract relative FP contract. We report that procurers' choice of contract format depend on unobserved project heterogeneity, consistent with the FDOT's belief that UP contract should be used for those projects with large project risk. Skewed bidding in UP contract is economically and statistically significant, suggesting UP may select an inefficient contractor that expect a large extent of cost-overruns. We build a simple and estimable model of bidding for contract, which is consistent with the empirical findings. Our empirical specification of the model allows for unobserved project heterogeneity in both expected cost and project risk. We found UP (resp. FP) is good for a project with a large (resp. small) amount of project risk and the estimated model rationalizes the FDOT's practice.

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10 Appendix

Table 12: Top 10 Contractors in FP and UP

Top Contractors in FP	# of FP contracts	Top Contractors in UP	# of UP contracts
APAC-Southeast	73	Anderson Columbia Co	103
Anderson Columbia Co	70	Community Asphalt	101
AJAX Paving	47	APAC-Southeast	73
Lane Construction	33	Ranger Construction	72
Better Roads	31	Weekley Asphalt Paving	71
L-J Construction Co	23	Hubbard Construction	51
C.W. Roberts Contracting	21	C.W. Roberts Contracting	47
Ranger Construction	19	General Asphalt Co	38
Hubbard Construction	16	AJAX Paving	34
D.A.B. Constructors	14	P&S Paving	32

10.1 State Dependence in Contract Formats

There is also a large amount of heterogeneity in the use of these two contractual arrangements across the district offices of the FDOT. Figure 9 plots the varying level of intensity in the use of FP relative to UP for the seven district offices across time. As a district office procures multiple projects at a time, the intensity of FP use is measured by the share of all FP projects over the sum of FP and UP projects procured during a year.

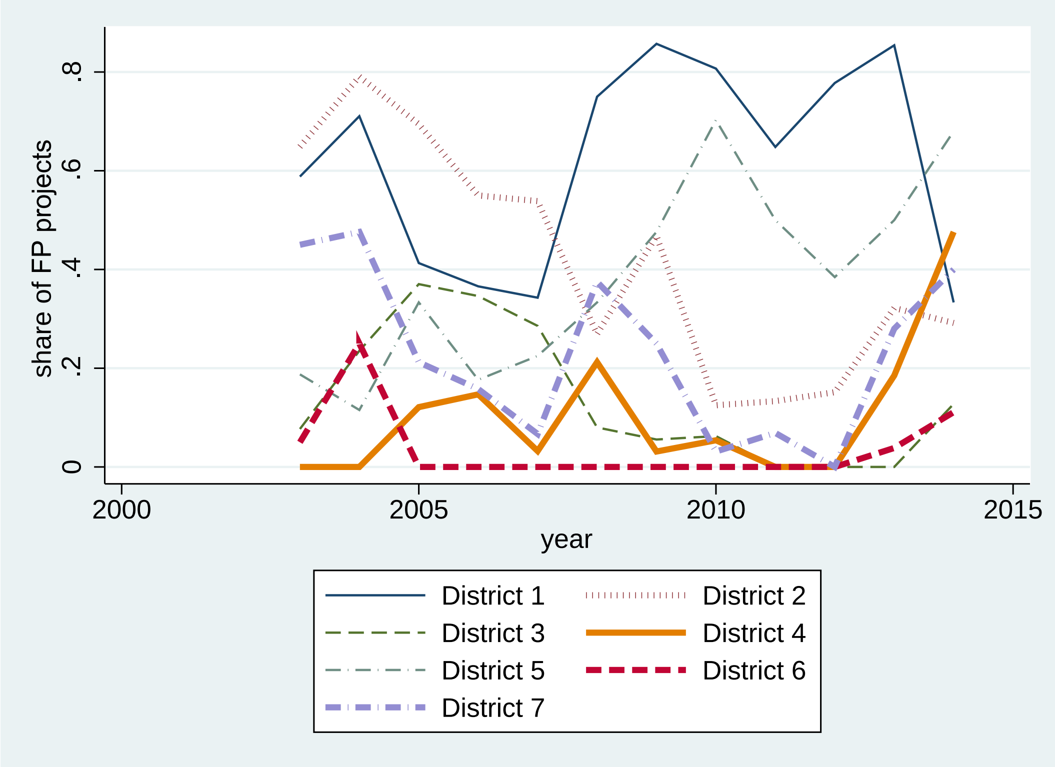

Figure 9: Use of FP over UP at each FDOT's district office

Two observations can be made from Figure 9. First, there is state dependency in the use of FP over UP while exhibiting much variation across time, which could be a product of turnover in project managers. Second, there is a common sharp increase in the use of FP over UP for the year following the financial crisis in 2008. In February 2009, the American Recovery and Reinvestment Act was signed into law. This stimulus package had an emphasis on infrastructure investment, which raised the number of procurements significantly. If the FDOT is capacity constrained, then the FDOT may choose to procure those additional projects via FP. UP could involve a higher transaction costs in order to estimate quantity of each construction item, and keep track of materials used. Indeed, the FDOT engineer mentions that the bulk of the administrative costs associated with UP comes from keeping track of materials used.

10.2 Derivation of (21)

I omit bidder subscript i here. A bidder's utility maximization problem in UP contract, who has a pseudo-cost c_u, is given by:

$$\max_{s_u} \quad [1-G_n(s_u|X)]^{n-1}\, u\,(s_u - c_u|X)\,,$$

where $u(.)$ is CARA utility function.

The first order optimality condition gives:

$$\frac{u(s_u-c_u|X)}{u'(s_u-c_u|X)} \quad = \quad \frac{1-G_n(s_u|X)}{(n-1)g_n(s_u|X)}.$$

Rewriting the left hand side of the above equation explicitly, we have:

$$\frac{u(s_u-c_u|X)}{u'(s_u-c_u|X)} \quad = \quad \frac{1}{\alpha(X)}\left(\exp\left\{\alpha(s_u-c_u)\right\}-1\right).$$

Rearranging the above first order condition, we have:

$$s_u - \frac{1}{\alpha(X)} ln\left(1+\alpha(X)\frac{1-G_n(s_u|X)}{(n-1)g_n(s_u|X)}\right) \quad = \quad c_u.$$

Since we know that $b_2 = \theta_2(X) + \frac{1}{\alpha(X)\sigma_2(X)}(e_2-1)$ and $c_u = \theta_1(X)e_1 + \theta_2(X) - \frac{1}{2\alpha(X)\sigma_2(X)}(e_2-1)^2$, we have:

$$s_u - \theta_2(X) - \frac{1}{\alpha(X)} ln\left(1+\alpha(X)\frac{1-G_n(s_u|X)}{(n-1)g_n(s_u|X)}\right) + \frac{\alpha(X)\sigma_2(X)}{2}(b_2-\theta_2(X))^2 \quad = \quad \theta_1(X)e_1.$$

Therefore, we have:

$$E\left[s_u - \theta_2(X) - \frac{1}{\alpha(X)} ln\left(1+\alpha(X)\frac{1-G_n(s_u|X)}{(n-1)g_n(s_u|X)}\right) + \frac{\alpha(X)\sigma_2(X)}{2}(b_2-\theta_2(X))^2|b_2, X\right] \quad = \quad \theta_1(X).$$

10.3 Proof of (3)

We show that the unique equilibrium bidding strategies and cost-overruns are multiplicatively separable in project characteristics X given the econometric specification in (23). First, consider non-lump-sum bidding strategy $b_2 \equiv b_2(\theta_2(X), \sigma_2(X), \alpha(X), e_2)$. We know that:

$$\begin{aligned} b_2(\theta_2(X), \sigma_2(X), \alpha(X), e_2) &= \theta_2(X) + \frac{e_2 - 1}{\alpha(X)\sigma_2(X)} \\ &= \left(\theta_2 + \frac{e_2 - 1}{\alpha\sigma_2}\right) \exp\{X\beta\} \\ &= b_2^0 \exp\{X\beta\}, \end{aligned}$$

where the second line follows directly from the normalization assumption (23). Thus, non-lump-sum bidding strategy is multiplicatively separable in X.

Second, we show that scoring strategy is multiplicatively separable in X. To see this, let us first consider the pseudo-cost $c_u \equiv \theta_1(X)e_1 + \theta_2(X) - \frac{1}{2\alpha(X)\sigma_2(X)}(e_{i2} - 1)^2$ and $c_u^0 \equiv c_u(0)$. We have:

$$\begin{aligned} c_u &= \left(\theta_1 e_1 + \theta_2 - \frac{(e_{i2} - 1)^2}{2\alpha\sigma_2}\right) \exp\{X\beta\} \\ &= c_u^0 \exp\{X\beta\}, \end{aligned}$$

and thus, pseudo-cost is multiplicatively separable in X. Now, conjecture that $s_u \equiv s_u(\theta_1(X), \theta_2(X), \sigma_2(X), \alpha(X), e_1, e$ $s_u^0 \exp\{X\beta\}$ constitutes an equilibrium scoring strategy. Consider first order condition with respect to score given by:

$$\begin{aligned} s_u - \frac{1}{\alpha(X)} ln\left(1 + \alpha(X)\frac{1 - G_n(s_u|X)}{(n-1)g_n(s_u|X)}\right) &= c_u \\ s_u^0 - \frac{1}{\alpha} ln\left(1 + \alpha\frac{1 - G_n(s_u^0|X = 0)}{(n-1)g_n(s_u^0|X = 0)}\right) \exp\{X\beta\} &= c_u^0 \exp\{X\beta\} \\ s_u^0 - \frac{1}{\alpha} ln\left(1 + \alpha\frac{1 - G_n(s_u^0|X = 0)}{(n-1)g_n(s_u^0|X = 0)}\right) &= c_u^0 \end{aligned}$$

where the second line follows because G_n is homogeneous of degree 0 while g_n is homogeneous of degree -1. Therefore, $s_u = s_u^0 \exp\{X\beta\}$ constitutes an equilibrium scoring strategy if s_u^0 is the equilibrium scoring strategy corresponding to pseudo-cost c_u^0. Since we know that the equilibrium is unique, $s_u = s_u^0 \exp\{X\beta\}$

is the unique equilibrium scoring strategy with $X \neq 0$.

Lastly, it is straightforward to see that $\Delta_2 = \Delta_2^0 \exp\{X\beta\}$ from the cost-overrun equation.

$$\begin{aligned} \Delta_2 &= b_2(e_2 - 1 + \epsilon_2) \\ &= b_2^0(e_2 - 1 + \epsilon_2)\exp\{X\beta\} \\ &= \Delta_2^0 \exp\{X\beta\} \end{aligned}$$

This completes the proof.