Auctions with Endogenous Participation and Quality Thresholds: Evidence from ODA Infrastructure Procurement

Antonio Estache
ECARES, Université Libre de Bruxelles

Atsushi Iimi
The World Bank

ECARES working paper 2009-006

ECARES
ULB - CP 114
50, F.D. Roosevelt Ave., B-1050 Brussels BELGIUM
www.ecares.org

AUCTIONS WITH ENDOGENOUS PARTICIPATION AND QUALITY THRESHOLDS: EVIDENCE FROM ODA INFRASTRUCTURE PROCUREMENT

February 2009

Antonio Estache
ECARES, Université Libre de Bruxelles

Atsushi Iimi[¶]
World Bank (FEU)

Abstract

Infrastructure projects are often technically complicated and highly customized. Therefore, procurement competition tends to be limited. Competition is the single most important factor toward auction efficiency and anti-corruption. However, the degree of competition realized is closely related to bidders' entry decision and auctioneer's decision on how to assess technical attributes in the bid evaluation process. The paper estimates the interactive effects among quality, entry and competition. With data on procurement auctions for electricity projects in developing countries, it is found that large electricity works are by nature costly and can attract only a few participants. The limited competition would raise government procurement costs. In addition, high technical requirements are likely to be imposed for these large-scale projects, which will in turn add extra costs for the better quality of works and limit bidder participation furthermore. The evidence suggests that the quality is of particular importance in large infrastructure projects and auctioneers cannot easily substitute prices for quality.

Key words: Public procurement; auction theory; infrastructure development; governance.

JEL classification: D44, H54, H57, C21.

[¶] We express our special thanks to Japan International Cooperation Agency (former Japan Bank for International Cooperation (JBIC) ODA Operations) for their collaboration in data collection and their insightful comments on an earlier version of this paper. We are grateful to Decio Coviello, Marisela Montoliu Munoz, Tomás Serebrisky and Tina Søreide for their various suggestions and comments. We also thank many seminar participants in the Chaire Bernard Van Ommeslaghe Conference at the Université Libre de Bruxelles.

I. INTRODUCTION

Infrastructure procurement is still a challenging task for governments, not only because public works are expensive but also because the nature of the works is often highly complicated and customized. Competitive bidding became prevalent among public procurement systems throughout the world, but how to design the auction mechanism remains difficult in practice, especially when bidder participation is endogenously determined. Typical are large-scale electricity projects. Governments or public entities, namely auctioneers, may be able to increase or decrease the number of bidders at will, but at certain expense.

The endogeneity of bidder participation is a complex issue in auction theory as well as its applications. As well known, competition is the single most important factor toward achieving economic efficiency and anti-corruptive allocation of an object through the competitive bidding. Even in the traditional fixed-*n* approach where the number of bidders is assumed fixed and commonly known by bidders, the equilibrium bid is expected to decrease with competition.[1] In the infrastructure procurement, it is of particular concern that the realized degree of competition is often limited, regardless of whether it is contracted out through a traditional method or public-private partnership (PPP) arrangement (e.g., Foster, 2005; NOA, 2007; Estache and Iimi, 2008a).[2]

Estache and Iimi (2008a) confirms the importance of intensifying competition to contain infrastructure procurement costs, but in a static sense. The previous analysis presumes that

[1] In the following sections of this paper, a government procurement auction is considered unless otherwise mentioned. Thus, bidder's cost of procuring the contracted-out work is a piece of unknown private information. The best contractor is a firm with the lowest possible cost parameter.

[2] According to the Private Participation in Infrastructure (PPI) database, the top 10 percent largest firms—defined by the number of transactions that each company obtained—were awarded about half of total infrastructure PPP contracts.

the number of bidding firms is fixed.[3] In many applications, however, a number of firms would potentially be interested in an object to be auctioned at the initial stage, but may not always enter that auction after all. Why? This question cannot be addressed in the traditional standard auction literature focusing on comparison of auctioneer's revenue between different institutions, but may be the center of interest of most auction practitioners.

There are two main reasons, though closely related to one another: entry cost and quality threshold. First, entry may be costly for firms. If a fixed positive cost is required for participating in an auction, bidders will enter until their expected profits are driven to the entry cost. At this level no more firms can expect nonnegative profits from new entry. High entry costs would reduce the optimal number of bidders and raise the profit guaranteed for a bidder with the lowest possible valuation or the highest possible procurement cost in the public work procurement context (McAfee and McMillan, 1987). Similarly, Levin and Smith (1994) finds a mixed strategy equilibrium composed of the entry probability, which is also a decreasing function of entry costs.[4] Under the circumstances where bidders decide whether to bid without knowing how many other rivals would participate, there is a clear tradeoff between the entry and competition effects when the number of potential bidders increases (Menezes and Monteiro, 2000). On one hand, intense competition is expected to induce bidders to reveal their true valuations, improving efficiency and reducing the equilibrium bid. On the other hand, enhanced competition would reduce the probability of each bidder's winning the object and thus his expected profit. Then, the realized number of contenders may become small, resulting in higher bid prices. Accordingly, auctioneer's expected revenue may or may not increase even if potential competition is augmented.

---

[3] From the empirical point of view, the fixed-n approach may not be inconsistent with the institutional setting of official development procurement, in which the number of bidders who were prequalified and actually participated in price competition is normally known among bidders prior to bidding.

[4] Unlike McAfee and McMillan (1987), Levin and Smith (1994) explicitly models who would enter the auction. Hence, in equilibrium each bidder would decide whether or not to participate, i.e., q^*, given a stochastic number of participating bidders, n.

The second reason for prospective bidders not participating is the presence of quality thresholds. Auctioneers often require participants to meet certain requirements prior to bidding, which may not be easy for some potential bidders to fulfill. In public infrastructure procurements, the main objective of requiring certain prerequisites, such as past experiences and managerial resources, from bidders is to ensure that the good quality of an object or public work be delivered at the agreed (lowest) cost within the designated period. Common practices are prequalification and other staged technical evaluation. Every aspect of "quality," which refers to anything the auctioneer cares about other than bid prices, makes the auction mechanism much complicated. The theory of multidimensional auctions shows that the two-stage bid evaluation system can implement the optimal mechanism maximizing auctioneer's expected profits (Che, 1993; Cripps and Ireland, 1994).[5] Prequalification is also expected to contribute to fostering a solid competitive marketplace, because well-qualified firms can price their bids with the knowledge that they are competing against only adequately qualified bidders with minimum competence criteria (ADB, 2006). However, a crucial shortcoming of multidimensional auctions is that the award process would be less transparent and more vulnerable to corruption; authorities can easily exploit their excessive discretion (Klein, 1998; Estache *et al*., 2008).

There is little consideration of the entry problem in the multidimensional auction context. In reality, the auctioneer's decision on whether to adopt such multidimensional methods may be dependent on how many bidders are expected to participate in the competitive bidding as well as the nature and technical complexity of public contracts. Highly specific qualification requirements would scale down the competition effect. Too rigid conditions might be considered an indication of corruption (Ware *et al*., 2007). Of course, firms can overcome their resource constraints, for instance, by pooling individual financial and experiential resources and making a bidding coalition. But whether joint bidding is pro- or anti-

[5] However, sequencing the price competition and the quality qualification makes no difference. The expected outcomes are the same regardless of whether quality or price is first examined, or even simultaneously (Cripps and Ireland, 1994).

competitive is also another controversial issue in auction theory.[6] Related to this, another alleged concern is that prequalification would rather help potential firms communicate and collude with each other. The prequalification stage certainly encourages firms to form joint ventures with other local or international firms, thereby benefiting from their resources and experience (ADB, 2006). At the same time, however, it may also provide many opportunities to facilitate communication among firms toward a collusive agreement.[7]

In principle, setting a quality threshold has three effects on the equilibrium bid. If quality is costly to produce and deliver, the equilibrium bid should increase. This is the true value attached to the required better quality of projects. Second, if quality is also costly to prepare, adding extra costs to potential contractors, the optimal number of bidders that are allowed to enter would decline in the presence of increased entry costs, whence limiting competition and raising the equilibrium bid. Third, however, if fewer bidders participate in an auction, the auctioneer may have an incentive to loosen the quality threshold as long as she values both bid price and quality. Under limited competition, quality may be subordinate to competition.[8] Hence, the optimal quality threshold maximizing auctioneer's expected profit might be relatively low. But lower thresholds would attract more bidders in turn. The total impact will be indeterminate and must be of necessity dependent on auctioneer's quality preference (see Annex for a simple example).

Because of these interactive effects among quality, entry and competition, the following empirical analysis adopts the treatment effect, instrumental variable, two-stage probit least

[6] For detailed discussion, see the joint bidding literature, such as Hendricks and Porter (1992), Krishna and Morgan (1997), Moody and Kruvant (1988) and Cho *et al*. (2002). In the infrastructure procurement context, Estache and Iimi (2008b) shows that joint bidding practices are largely incompatible with competition policy, except for a few cases, such as bidding coalition between local and foreign firms in road projects.

[7] In theory, bidders' free communication may lead to their voluntary bidding coalitions (specifically, two large joint ventures under the common value paradigm), though they remain competitive (Cho *et al*., 2002). The empirical literature suggests that more communication among a fixed set of players, particularly when they reside in close geographic proximity, would likely facilitate collusive practices (e.g., Porter and Zona, 1999; Gupta, 2002; Price, 2008).

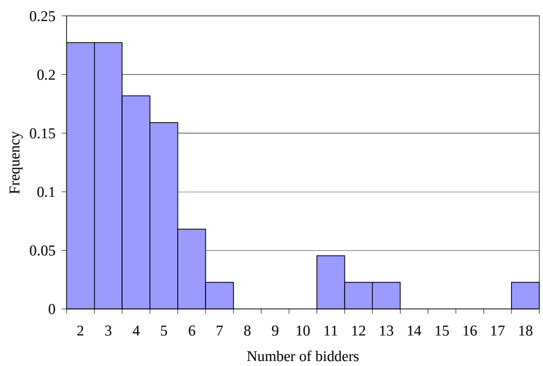
[8] Conversely, if a number of prospective firms are expected to participate, the auctioneer may prefer to request for higher qualities with little worry about possibly weakening competition.

squares, and three-stage least squares estimation methods. The remaining paper is organized as follows: Section II describes our data on public procurement auctions from official development assistance (ODA) financed infrastructure projects. It aims to overview the relationship between these elements on an informal basis. Section III develops our formal empirical models to estimate the equilibrium bid function with possible endogeneity of entry and quality considerations. Section IV presents and interprets our main empirical results.

II. An Overview of Electricity Project Procurement Auctions: Competition, Entry and Quality

Competition in public procurement auctions for infrastructure development is generally limited (Gupta, 2002; Foster, 2005). A fundamental reason is that a relatively small number of contractors are competent to participate in the competitive bidding for technically complex infrastructure projects. Classic are electricity projects. Normally, only two or three multinational enterprises may be able to make an entry to the selection process for large-scale electricity projects. Even in the road sector, which is deemed as relatively less complicated than other infrastructure sectors, the number of auction participants appears low at about 5 to 6 (Estache and Iimi, 2008a). In our sample composed of 44 electricity project auctions with 131 bids assisted by international aid donors, the average number of bidders is 4.7 with a median of 4 (Figure 1).

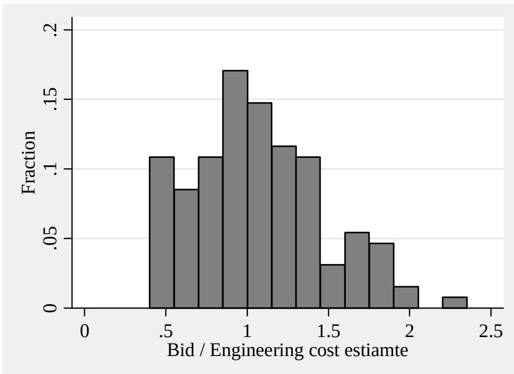
Figure 1. Degree of Competition in ODA-Financed Electricity-Sector Projects



Source: Author’s calculation.

The distribution of the observed bids normalized to their engineering cost estimates is roughly bell-shaped with a slightly thick tail on the left hand side. Most bids centered to unity as usual. However, some bids are about half of the normative engineering costs, and others are far more above the cost estimates (Figure 2). As expected in theory, intensifying competition is of particular importance to contain infrastructure procurement costs at the auction level. Even on a simple correlation basis, there is a weak tendency toward lower bids, i.e., procurement costs, as the number of competitors increases (Figure 3).[9] However, as shown, the majority of auctions attracted less than seven bidders. In such cases, the competition effect may remain debatable.[10]

Figure 2. Probability Distribution of Normalized Bid

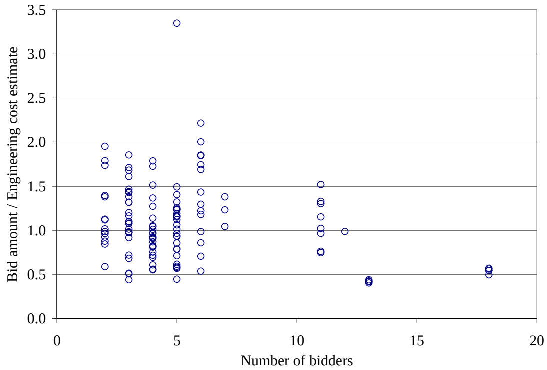


Source: Author's calculation.

[9] It is arguable whether each empirical auction is characterized as the independent private value or common value paradigm. In theory, they may lead to much different bidding patterns (e.g., Milgrom and Weber, 1982). Especially, in the latter setting, competition may increase the equilibrium bid due to the winner's curse effect (e.g., Paarsch, 1992; Klemperer, 1998; Hong and Shum, 2002; Athias and Nunez, 2006). In reality, any empirical auction may have both symmetric and asymmetric uncertainties for bidders. However, our belief is that in the ODA-related infrastructure procurements, auction-specific asymmetric uncertainty among bidders plays a relatively important role to determine the individual bid prices, whence in favor of choosing the independent private value paradigm. Typical are labor costs of individual firms. Even though the same amount of inputs is required to implement a project, unit costs (e.g., wages and equipment prices) are different across firms (Bajari *et al*., 2006). Also those private cost factors remain different across bidders even after the contract is awarded. By contrast, political instability and regulatory credibility are considered commonly uncertain components, which often matter to the public-private partnership (PPP) infrastructure auctions. However, for our traditional ODA project auctions to procure only specific construction works or equipment, those common factors are relatively less important than firm individual cost parameters. And Figure 3 and the following empirical analysis are suggestive, though not conclusive, evidence for a private value framework.

[10] For further detailed analysis, see Estache and Iimi (2008a).

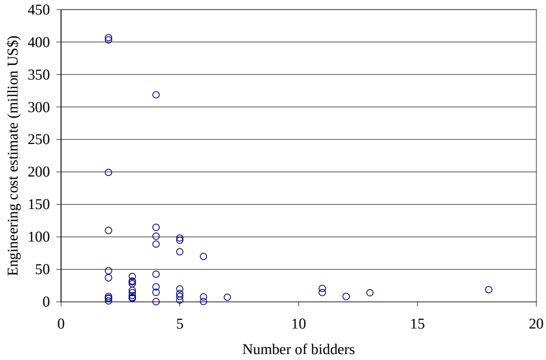
Figure 3. Competition and Normalized Bid Amount



Source: Author’s calculation.

One of the main reasons for limited competition in power project procurements is that the objects to be sold tend to be highly valuable and fewer companies would be able to implement such large projects. Our data are supportive of this. For pecuniarily small contracts the number of participating bidders can be small and large, but only a few companies seem to be able to enter into large projects (Figure 4). However, this does not explain all. Closely related to the size issue, requiring certain “quality” standards from prospective bidders is crucially affecting firms’ entry decision. Of particular note, however, it is empirically difficult to quantify the way technical aspects are evaluated throughout the bidding process, because of high project specificity. Required criteria differ from project to project. Nonetheless, we can observe whether executing agencies adopted the auction mechanisms to account for other attributes than bid prices in the bid evaluation process. Under the prequalification process, only bidders who meet basic financial, technical and experiential criteria are allowed to bid. In the two-envelope procedure, all potential bidders are requested to submit both price and technical proposal and an auctioneer opens the price bids only if the submitted technical proposal meets the required standards. In practice, there are wide variations of such these staged approaches. Even if prequalification or two-envelope is not formally adopted, large-scale infrastructure development projects usually rely on some staged evaluation process to disqualify incompetent applicants, regardless of their offered prices.

Figure 4. Number of Bidders and Size of Projects



Source: Author's calculation.

In our sample, 29 out of 44 electricity procurements were embedded with some auction mechanisms assessing technical elements substantially prior to price comparison. It is not surprising because electricity projects are complicated and need high technical capabilities from contractors. The figure includes the traditional two-envelope procedure and other staged process where bidders' substantial responsiveness is evaluated first. In many cases, financial and experiential responsiveness is checked, and technical scores are calculated based on bidders' proposals. At that stage, price bids may or may not be opened.[11] But if a bidder is disqualified due to technical reasons, his price bid will not be taken into consideration regardless of how much it is. Our sample reveals that the introduction of technical assessment would likely reduce the average number of bidders from 4.9 to 4.6. And the normalized average bid is higher when technical thresholds are established (Table 1). Nonetheless, the probability distributions of normalized bids show a mixed picture; relatively low bids look rather aggressive even with technical requirements imposed, possibly because of various interactive effects among competition, entry, quality and costs (Figure 5). This will be explored in the following sections.

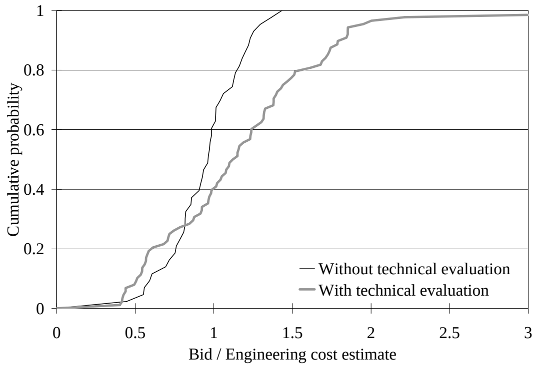
Table 1. Competition, Price Bids and Quality Evaluation

	Without technical evaluation					With technical evaluation				
	Obs.	Mean	Std.Dev.	Min	Max	Obs.	Mean	Std.Dev.	Min	Max
Number of bidders	15	4.93	2.89	2	12	29	4.59	3.67	2	18
Normalized bid	43	0.95	0.23	0.44	1.43	88	1.18	0.58	0.40	3.81

Source: Author's calculation.

[11] In the typical two-envelope procedure, price bids are not opened until the technical evaluation is finished.

Figure 5. Cumulative Probability Distribution Function of Normalized Bids by Technical Evaluation



Source: Author's calculation.

III. ESTIMATION METHODS AND DATA

Following the above discussion, to deal with endogeneity a system of three simultaneous reduced form equations is considered.[12] First, the symmetric equilibrium bid of bidder i at auction j (denoted by b_{ij}) is assumed a function of firms' cost parameters for that work (which are captured by observable project attributes X_j and bidder-specific characteristics Y_i), the presence of substantive technical evaluation (D^{TE}) and the number of realized bidders (n_j). This follows the traditional empirical auction literature (e.g., Porter and Zona, 1993; Gupta, 2002; Iimi, 2006). Notably, the dependent variable b_{ij} is both winning and losing bids, which are considered equally informative in the first-price sealed-bid format.

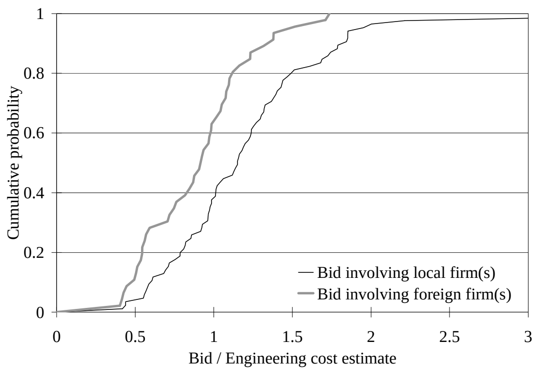
$$\ln b_{ij} = \alpha_1 \ln n_j + \alpha_2 D_j^{TE} + X_j'\beta_1 + Y_i'\beta_2 + \varepsilon_1 \quad (1)$$

X is primarily composed of installed generation capacity in MW (*GCAP*), total length of transmission lines in km (*LINE*), maximum transformation capacity of erected substations in

[12] An obvious alternative is the structural econometric estimation, such as Paarsch (1992), Guerre *et al*. (2000) and Bajari *et al*. (2006). However, the analysis including endogenous entry and technical considerations is not tractable using currently available methods, though Annex provides an illustrative example to materialize the structure model. Our following analysis takes a reduced form approach but is consistent with the structure envisaged in Annex.

kV (*SUBS*), and estimated engineering costs (*COST*). These variables are all logarithmic in the estimation models. Two dummy variables are also included: D^{DAM} for dam construction work, which normally requires additional large costs, and D^{CIVIL} for civil works in opposition to equipment supply, which may or may not be costly for contractors. Ten dummy variables for project countries are included as well. Y_i consists of a number of bidder nationality dummy variables. It is likely that nationalities influence bidders' underlying cost parameters. In general, local and foreign bidders would have different cost advantages and disadvantages, whence behaving differently in an auction. While local enterprises tend to have comparative advantage in labor costs, multinational companies usually have more experiences of development projects and are familiar with advanced technology. In the case of electricity projects, foreign companies may have the clear advantage because of their technological competence (Figure 6).

Figure 6. Cumulative Probability Distribution Function of Normalized Bids by Nationality



Source: Author's calculation.

The second equation is the number of participants *n*, which is determined by project-specific characteristics *X* and other exogenous variables representing the extent to which local and international contractors could accommodate public works. An increase in the amount of similar infrastructure development projects implemented in a country and the rest of the developing world during the past years would make prospective contractors busier, leaving fewer companies to bid on new works (Bajari *et al.*, 2006). The idea is consistent with Porter and Zona (1993) and others (e.g., Price, 2008). In our models, specifically, Z_j includes the amounts of energy-sector ODA projects received by each recipient country and the developing world for the past three years. Two dummy variables are also potentially included for projects in China and projects assisted by JBIC. In China, there are a number of prospective firms, thus likely leading to a larger number of *n*, holding everything the same. Also, potential bidders may have different preferences to aid projects by multi- and bi-lateral donors.

$$\ln n_j = \alpha_3 D_j^{TE} + X_j' \beta_3 + Z_j' \beta_4 + \varepsilon_2 \qquad (2)$$

Finally, the auctioneer, namely executing agency, is supposed to decide whether to adopt the substantial technical evaluation system, depending on technical specifications of each project X_j as well as the expected degree of competition (n_j).

$$D_j^{TE} = \alpha_4 \ln n_j + X_j' \beta_5 + \varepsilon_3 \qquad (3)$$

Therefore, the system has three endogenous variables: $\ln b$, $\ln n$ and D^{TE} in three equations (1) to (3).

The data are collected from 44 procurement auctions for 21 electricity projects in 13 countries assisted by the World Bank and a bilateral donor agency, Japan Bank for International Cooperation (JBIC)[13] for the period: 2000 to 2007.[14] The sample coverage is by no means unbiased by country; this is mainly because our sample partly comes from the available procurement data on large electricity projects financed by the Japanese development assistance, which has been concentrated in several countries in Asia (Table 2).

---

[13] JBIC ODA Operations will be merged with the Japan International Cooperation Agency (JICA) in October 2008.

[14] All bids and engineering cost estimates are normalized to the constant 2005 U.S. dollar terms.

Table 2. Sample Distribution by Country

	Number of projects	Number of contracts	Number of bids
Albania	1	1	4
Azerbaijan	1	2	5
China	7	15	43
Egypt	1	2	8
India	1	1	3
Indonesia	1	3	3
Kenya	1	3	14
Malaysia	2	2	2
Nigeria	1	2	11
Sri Lanka	1	1	3
Tanzania	1	4	13
Uganda	1	2	3
Viet Nam	2	6	19
Total	21	44	131

Source: Author's calculation.

As shown in Table 3, the sample contracts are also considerably heterogeneous in technical terms. The average installed generation capacity is 125 MW with a maximum of 1,200 MW. If a contract is irrelevant to generator erection, then the capacity is set at a very small but nonnegative number (to avoid logarithms of zero). The length of transmission lines is calculated by adding all installed lines, regardless of transmission capacity (kV). The length is about 50 km on average but ranges from several to 760 km. The capacity of substation equipment (including transformer, switchgear and control equipment with low voltage supply equipment) also varies widely between 33 kV and 500 kV. About half auctions adopted the substantive technical evaluation process, such as the two-envelope procedure. The average number of participating bidders is 5.5, but the distribution is very skewed (as seen in Figure 1).[15] About two-thirds are associated with civil works, rather than equipment delivery. In terms of engineering cost estimates some of the contracts are valued at less than one million dollars, but others exceeded 400 million dollars.

[15] This average is simply calculated in the sample including both winning and losing bids. On an auction basis, the average number of bidder is 4.7 and the median is 4.

Table 3. Summary Statistics

Variable	Abbr.	Obs.	Mean	Std.Dev.	Min	Max
Bid amount 1/	*b*	131	50.61	73.77	0.22	435.49
Number of bidders	*n*	131	5.47	3.67	2.00	18.00
Dummy for technical evaluation	D^{TE}	131	0.67	0.47	0	1
Dummy for dam contracts	D^{DAM}	131	0.10	0.30	0	1
Dummy for civil work	D^{CIVIL}	131	0.65	0.48	0	1
Installed generation capacity (MW)	*GCAP*	131	125.99	284.51	0	1,200.00
Length of transmission lines (km)	*LINE*	131	50.69	153.39	0	765.00
Max capaity of substations (kV)	*SUBS*	131	65.46	136.48	0	500.00
Engineering cost estimate 1/	*COST*	131	46.93	67.80	0.36	406.61
Past transport ODA in the world 1/	*WAID*	131	6,980	615	6,622	9,807
Past transport ODA in each country 1/	*CAID*	131	413	341	15	1,339

1/ In millions of constant 2005 U.S. dollars.

Source: Author's calculation.

Regarding additional exogenous variables Z_j, two numbers are created: *CAID* is the amount of gross ODA disbursement in the energy sector that each project host country received for the three years before the award of a particular contract. *WAID* is similarly defined as the total ODA amount distributed to the energy sector all over the developing world. Both are in constant 2005 U.S. dollar terms. These are lagged variables and considered independent of firms' bidding behavior in individual current auctions. But they would still likely influence firms' capabilities to enter the competition. Our sample data represent only some 10 percent of total energy-sector ODA (Table 4). Several domestic and multinational enterprises have repeatedly been participating in the ODA-related infrastructure market.[16] If firms are already engaged in a large number of similar development projects, fewer bidders would be willing to bid on further works. It is also noteworthy that *CAID* and *WAID* are not invariant across auctions within a country, if contracts are awarded in different years. In the estimation models, they are in logarithm. The aid data originate from the OECD Creditor Reporting System database.

Table 4. Total Transport-Sector ODA Projects
(Millions of constant 2005 U.S. dollars)

	2000	2001	2002	2003	2004	2005	2006	2007
Total amount of ODA	55,112	54,580	62,207	76,362	73,935	94,407	95,286	
Of which, infrastructure 1/	10,817	9,829	8,119	8,344	13,764	13,063	11,979	
Of which, energy	1,758	2,103	2,706	3,467	6,024	3,238	3,720	
Total cost estimates of our sampled projects	294	407	328	306	632	508	29	89

1/ Including energy, water and sanitation, transport and storage, and communication.

Source: Author's calculation based on own data and OECD.Stat.

[16] There is one firm which solely or jointly obtained five large contracts in our sample. Nonetheless, the market concentration generally appears modest. The concentration ratios of the top five firms in terms of the number of contracts awarded in our sample is 22 percent in electricity project procurements (Estache and Iimi, 2008c).

To estimate Equations (1) to (3) simultaneously, the conventional three-stage least squares estimation method (Zellner and Theil, 1962) is adopted. For computational simplicity this model needs to assume linearity all over the system, despite the dichotomy of D^{TE}. But all the equations can be estimated together to conclude the ultimate effects of competition, entry and technical considerations.

In addition, several different estimation approaches are used to estimate two of the three equations in the system. To estimate Equations (2) and (3) together, the two-stage probit least squares model is applied (Maddala, 1983). Notably, D^{TE} is endogenous and dichotomous, while n is a positive number.[17] Therefore, the two-stage approach is taken where the probit and ordinary least squares (OLS) models are first performed for D^{TE} and $\ln n$, respectively, and then the standard errors are corrected by the estimated individual variance-covariance matrices and a correlation between the two equation.[18] The system will explain how bidders make an entry decision and how the auctioneer reacts to their entry via requiring quality standards.

To estimate Equations (1) and (2) simultaneously, the conventional instrumental variable technique is applied. In this case, the endogeneity of D^{TE} is presumed insignificant. Although this may not hold in the formal model as will be shown, it roughly reveals how bidders choose to enter into a particular type of auction, and given that, whether or not the auction is pro-competitive.

Finally, the treatment effect model is used to estimate Equations (1) and (3), because D^{TE} is a binary endogenous choice in the equilibrium bid. This will indicate the possible impact of technical considerations on project procurement costs under the assumption that n is fixed.

[17] Technically, in addition, the second endogenous variable n is typical of count data. To avoid further complication, however, n is treated as a continuous positive variable.

[18] To identify the system of equations, one exogenous variable, *CAID*, is included in the equation of D^{TE} at the second stage. Note that in the two first-stage regressions both *WAID* and *CAID* are used as instruments.

IV. ESTIMATION RESULTS AND IMPLICATION

Entry, quality and bids

With all potential endogeneities taken into account, a three-stage least squares estimation is performed (Table 5). The equation of $\ln n$ shows that the number of bidders would be limited for large-scope power generation works. Possibly related to this, the technical evaluation process requiring non-price criteria from potential firms would restrict participants considerably. As will be seen in the following, limited competition would raise bids. This is an important anti-competitive effect of pursuing project quality. It also shows that the coefficients of past aid disbursements in the energy sector are both negative. It means that if firms are already devoted to other electricity development projects elsewhere, then fewer bidders could apply for new public contracts and competition will be modest. This means that firms are physically and financially constrained. If there are a large amount of backlogs in the relevant industry and if the project requires high technical standards, one cannot expect the large competition effect in public auctions.

On the other hand, the equation of N indicates that more firms are willing to participate in public tenders for civil works and highly valuable contracts. Civil works can be considered more dependent on firm-specific cost conditions, such as labor costs, than contracts of simple equipment delivery. Hence, more local companies may be able to participate in the bidding process, particularly for distribution line works. High value contracts would also provide more profit opportunities for any bidders, whence inducing more firms to enter. By type of contract work, large power transmission and distribution line erection contracts are relatively easier for potential firms to enter the competition.

In the equation of D^{TE}, the coefficient of the number of bidders is positive at 0.092 but not statistically significant. It means that when the expected degree of competition is limited, auctioneers may have an incentive to release the thresholds, but not always. In the system equation context, in addition, the equation of D^{TE} is found endogenous; the Hausman test statistics is estimated at 47.9.[19] All the indications suggest that regardless of the level of competition, auctioneers would exogenously make their decision to adopt the substantial technical evaluation process. With our data, auctioneers tend to use it for civil work contracts and large power generation procurements. It suggests that the quality is of particular importance in large infrastructure projects, and auctioneers cannot easily substitute prices for quality even though competition is limited in such projects.

Regarding the bid equation, high priority attached to technical aspects would have significant impacts on the equilibrium bids. The coefficient is 0.43; this is considered the pure cost of requiring higher quality specifications, exclusive of the indirect impact of limited competition stemming from high technical thresholds.[20] The endogenous impact of the technical evaluation is controlled in the equation of $\ln n$ as mentioned above, and the overall impact of competition is estimated at –0.56. That is, the realized competition is still a driving force toward lower procurement costs. The other coefficients are largely consistent with the above two-equation estimation results. Civil works are costly, but more applicants can be expected. Power generator installation is also costly, and fewer enterprises may be able to enter the procurement process. In addition, the technical evaluation is normally required for power generator works. By contrast, more bidders may participate in larger transmission and distribution contracts. And the coefficient of the engineering cost estimate is close to unity, as expected.

[19] On the other hand, the number of bidders does seem to be exogenous in the equation of D^{TE}. The Hausman test statistics is –35.23, which can be interpreted as strong evidence that the exogeneity hypothesis cannot be rejected.

[20] Formally, the Hausman exogeneity test cannot be rejected in the bid equation. For auction participants, both n and D^{TE} seem to be exogenously given at the time of bidding.

Table 5. Three-Stage Least Squares Estimation of Bids, Entry and Technical Evaluation

Estimation method	Three-stage least squares		
	3rd stage	3rd stage	3rd stage
Dependent variable	ln *b*	ln *n*	D^{TE}
ln *n*	–0.561 **		0.092
	(0.230)		(0.110)
D^{TE}	0.430 ***	–0.214 **	
	(0.163)	(0.099)	
D^{DAM}	–0.022	–0.223	–0.037
	(0.107)	(0.144)	(0.138)
D^{CIVIL}	0.305 **	0.512 ***	0.180 *
	(0.139)	(0.105)	(0.098)
ln *GCAP*	0.008 **	–0.008 *	0.019 ***
	(0.004)	(0.005)	(0.004)
ln *LINE*	0.004	0.022 ***	–0.003
	(0.008)	(0.005)	(0.005)
ln *SUBS*	0.012 ***	0.007	0.007
	(0.004)	(0.005)	(0.005)
ln*COST*	1.024 ***	0.105 ***	–0.129 ***
	(0.053)	(0.037)	(0.036)
ln*WAID*		–1.772 ***	
		(0.541)	
ln*CAID*		–0.013	
		(0.044)	
Constant	14.415 ***	17.184 ***	1.021 ***
	(0.336)	(4.781)	(0.208)
Obs.	131		
R-squared	0.971	0.487	0.172
Wald chi2	4535.22	125.74	28.30
Recipient country dummy	Yes	China	No
Bidder nationality dummy	Yes	No	No
Donor dummy	Yes	Yes	No

Note that the standard errors are shown in parentheses. *, **, and *** indicate the 10%, 5% and 1% significance levels, respectively.

There are at least two particular remarks to interpret the estimation results correctly. First, our quality measurement is far from perfect. It merely captures a part of quality attributes related to infrastructure projects. The technical evaluation embedded in the ordinary infrastructure procurement process helps to ensure the contract implementation as agreed, but only given the main scope of the contract. Whether the project design is *technically* best is a different question that the above discussion cannot answer. This issue may have to be addressed by the cost benefit or least cost analysis and careful review of alternative designs at the much earlier stage, i.e., at the timing of project appraisal. In addition, whether the project was ex post implemented as contracted is also left unsolved. This also requires a different measure to assure the *quality* of projects, such as project monitoring and auditing.

Second, the analysis ignores the possible cost of auctioneers. It may be administratively costly for executing agencies to divide a project into a number of small lots and coordinate them. Notably, however, recent rapid developments in information and communication technology (ICT) allow to reduce administrative costs of public procurement dramatically through e-procurement or e-government. Along with all these complementary institutions, auctioneers could pursue more competition and better quality simultaneously in infrastructure procurement.

Entry and quality

When the bidder entry equation is estimated simultaneously with the auctioneer's decision on whether to adopt the substantial technical evaluation, it is found that auctioneers are more likely to use such a mechanism as the number of participants increases (Table 6). In addition, the hypothesis that this quality standard decision is exogenous can be rejected according to the Hausman exogeneity test, for which the chi-squared test statistics is estimated at 16.44. This result is not compatible with the above three-equation system estimation. But it is interesting to interpret the result, because it means that auctioneers would react to enhanced competition by increasing greater emphasis on quality aspects. Conversely, if the number of bidders is limited, auctioneers would not impose too severe quality requirements. Without doubt, however, this compromise would result in the worst-case scenario; limited competition will raise procurement costs, and project quality may not be able to be ensured.

The two-stage probit least squares model also shows that auctioneers may prefer to adopt the technical evaluation systems for procuring larger electricity generators and civil works. Regarding bidders' entry decision, the first-stage regression indicates that the number of bidders in equilibrium seems to decrease with the installed generator capacity and the volumes of past foreign aid in the energy sector. Large power generation projects could attract fewer bidders possibly due to technical difficulties, and the number of expected participants would be small when potential contractors are already engaged in other electricity development projects. However, the statistical significance of these coefficients appears weak in the second stage regression where D^{TE} is treated as potential endogenous, although the exogeneity hypothesis of D^{TE} cannot be rejected formally by the Hausman test (the test statistics is negative). The impact of adopted technical evaluation systems is also far from significant; the coefficient is positive (0.162).

Table 6. Two-Stage Probit Least Squares Model for Entry and Technical Evaluation

Estimation method	Two-stage probit least squares			
	1st stage	1st stage	2nd stage	2nd stage
Dependent variable	ln *n*	D^{TE}	ln *n*	D^{TE}
ln *n*				2.589 ***
				(0.737)
D^{TE}			0.162	
			(0.874)	
D^{DAM}	–0.170	–0.666	–0.062	–0.039
	(0.153)	(0.727)	(0.637)	(0.749)
D^{CIVIL}	0.451 ***	0.984 ***	0.291	0.024 ***
	(0.109)	(0.384)	(0.894)	(0.490)
ln *GCAP*	–0.010 *	0.038 *	–0.016	0.085 ***
	(0.005)	(0.021)	(0.035)	(0.020)
ln *LINE*	0.023 ***	–0.012	0.025 **	–0.066 ***
	(0.005)	(0.019)	(0.012)	(0.023)
ln *SUBS*	0.005	0.044 **	–0.002	0.026
	(0.005)	(0.020)	(0.041)	(0.022)
ln*COST*	0.110 ***	–0.205	0.144	–0.613 ***
	(0.039)	(0.155)	(0.193)	(0.154)
ln*WAID*	–1.856 ***	1.637	–2.122	
	(0.579)	(2.427)	(1.475)	
ln*CAID*	–0.009 ***	–0.054		0.187
	(0.047)	(0.158)		(0.150)
Constant	17.761 ***	–13.235	19.910 *	–2.189 *
	(5.124)	(21.465)	(12.225)	(1.277)
Obs.	131	131		131
R -squared	0.462			
F -statistics	10.30			
LR chi2		64.17		49.83
Recipient country dummy	China	China	China	No
Bidder nationality dummy	No	No	No	No
Donor dummy	Yes	No	Yes	No

Note that the standard errors are shown in parentheses. *, **, and *** indicate the 10%, 5% and 1% significance levels, respectively.

Entry and bids

The instrumental variable model where the equilibrium bid function is estimated with the number of bidders *n* instrumented shows more results on the bidder entry preferences. The first stage regression on $\ln n$ indicates that fewer bidders would participate in the auctions for dam construction, and civil works and more valuable contracts could attract more participants (Table 7). Large-scale power transmission and distribution projects look more attractive for potential contractors, but there is no significant evidence that larger generation and substation works could have more bidders. This is consistent with the above two-stage probit least squares model. It can be interpreted as the particular significance of economies of scale in transmission and distribution works.[21] With the technical evaluation process introduced, fewer firms seem to be allowed to enter; the coefficient of D^{TE} is negative but not statistically significant.

Regarding the impact on the equilibrium bid, the second stage regression reveals that more competition leads to lower procurement costs as expected. However, the exogeneity of n may not be able to be rejected at the conventional significance level. The Hausman exogeneity test statistics is estimated at 0.14. Besides n, Table 6 shows that larger projects, especially in terms of generation and substation capacities, would be more costly. The equilibrium bid would also be higher if bidders are supposed to be assessed technically before the price comparison. This follows natural expectations. It is worth recalling that in this instrumental variable estimation, another potential simultaneous equation associated with auctioneer's technical consideration decision is ignored.

Quality and bids

The treatment effect model more clearly highlights the possible effect of involving technical thresholds on the equilibrium bid. D^{TE} is treated as potentially endogenous in the equation of $\ln b$. It is confirmed that auctioneers would prefer to place more emphasis on technical assessment for large electricity generation and substation projects.[22] And this quality consideration will bring about additional procurement costs; the coefficient of D^{TE} is estimated at 0.709, which is significantly different from zero. In this estimation model, however, D^{TE} may be exogenous, because the Hausman exogeneity test statistics is rather low at 0.60. Therefore, at the entry decision stage, the technical standard adoption may be endogenous (as shown above), but the price bidding stage, the technical requirements are give to potential bidders, and they would likely reflect extra costs on their price bids. Notably,

[21] See Estache and Iimi (2008a) for more detailed discussion on potential economies of scale in infrastructure procurements.

[22] The dummy variables for dam and civil works are excluded for convergence purposes. However, the main results have been found unchanged even if the system is estimated by the two-stage estimation technique.

the equilibrium bid function still looks pro-competitive with respect to *n*; more bidders lead to lower procurement costs.

Table 7. IV and Treatment Effect Regressions on Bids

Estimation method	2SLS		Treatment effect	
	1st stage	2nd stage	1st stage	2nd stage
Dependent variable	ln *n*	ln *b*	D^{TE}	ln *b*
ln *n*		–0.495 **	0.274	–0.420 ***
		(0.231)	(0.245)	(0.070)
D^{TE}	–0.059	0.498 ***		0.709 ***
	(0.406)	(0.140)		(0.196)
D^{DAM}	–0.301 **	–0.005		0.018
	(0.140)	(0.107)		(0.092)
D^{CIVIL}	0.528 ***	0.270 *		0.226 ***
	(0.132)	(0.140)		(0.082)
ln *GCAP*	0.001	0.008 **	0.049 ***	0.005
	(0.006)	(0.004)	(0.014)	(0.004)
ln *LINE*	0.030 ***	0.002	–0.006	–0.0004
	(0.005)	(0.008)	(0.016)	(0.004)
ln *SUBS*	0.002	0.012 ***	0.026 *	0.011 ***
	(0.006)	(0.004)	(0.015)	(0.004)
ln*COST*	0.129 *	1.021 ***	–0.357 ***	1.032 ***
	(0.068)	(0.053)	(0.120)	(0.048)
ln*WAID*	1.028			
	(2.143)			
ln*CAID*	0.443 ***			
	(0.157)			
Constant	–10.419	14.309 ***	1.829 ***	14.009 ***
	(19.369)	(0.328)	(0.609)	(0.301)
Obs.	131	131	131	131
R-squared	0.713	0.972		
F-statistics	6.48			
Wald chi2		4536.80		4014.84
Recipient country dummy	Yes	Yes	No	Yes
Bidder nationality dummy	Yes	Yes	No	Yes
Donor dummy	Yes	Yes	No	Yes
ρ				–0.521
				(0.316)
LR test statistics: $\rho=0$				0.70

Note that the standard errors are shown in parentheses. *, **, and *** indicate the 10%, 5% and 1% significance levels, respectively.

V. Conclusion

Infrastructure procurement is a challenging task for governments. Infrastructure projects are often technically complicated and highly customized. Because potential bidders that are competent for large-scale infrastructure works are relatively limited, procurement competition tends to be limited. Electricity projects are typical. In most cases of our sample, only two or three bidders participated in each auction.

Without doubt competition is the most important factor toward efficiency and anti-corruption. However, the degree of competition that one can expect is closely related to bidders' entry decision and auctioneer's decision on how to assess non-price (technical) attributes in the bid evaluation process. The current paper casts light on the potential interactive effects among quality, entry and competition, by estimating the system of simultaneous equations with data on procurement auctions for large electricity projects in developing countries.

It is found that the decision to adopt the technical evaluation method is endogenously made while potential contractors are considering whether they would enter the auction process. If certain technical aspects are taken into consideration regardless of prices, the equilibrium bids would increase significantly due to extra costs required to meet higher quality standards. In addition, high technical requirements would reduce the number of participants. When the expected competition is going to be limited, auctioneers may have an incentive to loosen the thresholds. But this feedback is found insignificant because the quality is of particular importance in large-scale infrastructure projects. In general, technically large electricity projects are not only costly by nature but also can attract only a few potential bidders, resulting in less efficiency. Moreover, the technical requirements are more likely to be imposed on large projects so that bidder participation would be even more limited. This is the revealed underlying mechanism for limited competition in procurement auctions for large electricity projects.

ANNEX. AN EXAMPLE OF AUCTION WITH ENDOGENOUS ENTRY AND QUALITY THRESHOLD

A simple government procurement auction with a predetermined quality threshold is considered under the independent private value paradigm. A three-stage sealed-bid first-price format is assumed: bidders' entry decision, auctioneer's quality threshold selection, and conventional competitive bidding. Suppose that given a private cost parameter $\theta_i \in [\theta_L, \theta_H]$, which is distributed according to a density probability distribution function $f(\theta)$, each bidder is requested to submit price bid b_i and quality q_i simultaneously. They do not directly care about quality (meaning that a higher quality of project does not increase bidder profits), but quality is costly to deliver, i.e., bidder i's cost function is $c(\theta_i, q_i)$. Assume that $\frac{\partial c}{\partial \theta_i} > 0$, $\frac{\partial c}{\partial q_i} > 0$ and $\frac{\partial^2 c}{\partial q_i^2} > 0$. It means that quality is quite expensive; bidders' procurement costs increase with quality in a convex fashion. Bidders, once entering the selection process, have to pay entry cost k, and thus the bidder i's payoff function is:

$$\pi_i = \begin{cases} b_i - c(\theta_i, q_i) - k & \text{if } b_i = \min_{j \in n}\{b_j\} \text{ and } q_i \geq \xi \\ -k & \text{otherwise} \end{cases}$$

where ξ is the quality threshold.

A solution is characterized through a backward step. At the bidding stage, a symmetric equilibrium bid function is:

$$b(\theta_i, q_i) = c(\theta_i, q_i) + \pi_H + \frac{\int_{\theta_i}^{\theta_H} c_\theta(t, q_i)[1 - F(t)]^{n-1} dt}{[1 - F(\theta_i)]^{n-1}}$$

This is merely a variation of Che's (1993) model but includes a positive entry cost k. Note that π_H is basically composed of k and the profit guaranteed to a bidder with the highest possible cost parameter. Because quality is costly for bidders, the equilibrium quality bid must be set at the minimum requirement, $q_i = \xi$.

Given this symmetric equilibrium, the auctioneer is supposed to maximize its expected profit with respect to quality and select the optimal threshold ξ^*:

$$\xi^* \in \arg\max_q V(q) - E\left[\min_j \left\{b_j\left(\theta_j, q\right)\right\}\right]$$

where $V(q)$ is the value attached to the quality by the auctioneer. Assume that $\frac{\partial V}{\partial q} > 0$ and $\frac{\partial^2 V}{\partial q^2} < 0$; the quality is valuable but in a concave fashion. And the auctioneer contracts out the project at the (expected) lowest bid.

Finally, at the beginning of the game, bidders are assumed to enter as long as their expected profits are nonnegative (McAfee and McMillan, 1987). Before observing his cost parameter, the ex ante expected profit from entry for any bidder is:

$$E(\pi_i) = \pi_H + \int_{\theta_L}^{\theta_H} \int_{\theta_i}^{\theta_H} c_\theta(t, \xi)\left[1 - F(t)\right]^{n-1} dt f(v) dv$$

This must be equal to k. Hence, the optimal number of participants n^* satisfies the following:

$$\pi_H + \int_{\theta_L}^{\theta_H} c_\theta(t, \xi)\left[1 - F(t)\right]^{n^*-1} F(t) dt = k$$

For illustrative purposes, a numerical example is considered and several comparative static effects are investigated to see the equilibrium behavior in terms of entry and quality threshold. Assume that θ is uniformly distributed from zero to unity. And assume the following functional forms: $c(\theta_i, q_i) = \theta_i q_i^2$ and $V(q) = q^{1/2}$. Moreover, $\pi_H = 0$ for simplicity. Then, the bidder equilibrium strategy given *n* and ξ is:

$$\begin{cases} b_i^* = q_i^2 \left(\theta_i + \dfrac{1-\theta_i}{n} \right) \\ q_i^* = \xi \end{cases}$$

Hence, no bidder reveals his true cost as usual, and their price bids are inflated by the quality factor. As competition increases, their bids would approach their true costs (as often called the competition effect).

Note that the equilibrium bid is distributed according to $G(b) = \frac{1}{n-1}\left(\frac{nb - \xi^2}{\xi^2}\right)$ for

$b \in \left[\frac{\xi^2}{n}, \xi^2\right]$, and the expected winning bid is $E[b_{(1)}] = \left[\frac{n}{n-1}\right]^n \frac{n}{\xi^2} \int_{\frac{\xi^2}{n}}^{\xi^2} x \left(1 - \frac{x}{\xi^2}\right)^{n-1} dx$.

Therefore, given *n*, the auctioneer maximizes its expected profit with respect to the quality requirement ξ:

$$\max_{\xi} E[\pi_0] = \xi^{1/2} - \frac{2\xi^2}{n+1}$$

Then, the optimal quality threshold is set at:

$$\xi^* = \frac{(n+1)^{2/3}}{4}$$

With well-behaved functional forms assumed (as mentioned above), the optimal *q* is strictly positive, meaning that the auctioneer always prefers to set a certain quality threshold $\xi^* > 0$. In addition, the auctioneer would raise the threshold as the number of participating bidders increases. This is essentially because price and quality are both desirable and substitutable for the auctioneer. Intense competition would bring down the equilibrium bid as shown above. Hence, quality tends to become relatively more valuable for auctioneer, and she might raise the threshold. The total effect on the equilibrium price will be indeterminate, because there is a clear tradeoff between strengthened competition and higher quality requirements.

The optimal number of bidders is determined by:

$$k = \frac{(n^* + 1)^{1/3}}{16n^*}$$

Not surprisingly, $\frac{\partial n^*}{\partial k} < 0$; higher entry costs would reduce the optimal number of bidders.

A practical implication is straightforward: Suppose that for some exogenous reason (for example, through introducing e-procurement) the entry cost for potential bidders declines. Then, more bidders would likely decide to participate in the procurement process. Intensified competition would lead to lower bid prices. However, the auctioneer who lays great emphasis on quality (in addition to prices) may desire to raise the required quality threshold, for example through tightening the prequalification and technical evaluation systems. Higher quality requirements would add additional costs on individual bid prices. Accordingly, the equilibrium bid, or the expected public procurement costs may or may not decrease with entry costs alone. It must be of necessity dependent on various factors, such as bidders' cost structure including quality aspects, and the extent to which the quality matters to the auctioneer, or more precisely the public in the government procurement case.

REFERENCE

ADB. 2006. *Prequalification of Bidders User's Guidelines*, Asian Development Bank.

Bajari, Patrick, Robert McMillan, Steven Tadelis. 2006. Auctions versus negotiations in procurement: an empirical analysis, *Journal of Law, Economics and Organization*, forthcoming.

Che, Yeon-Koo. 1993. Design competition through multidimensional auctions. *Rand Journal of Economics*, Vol. 24, pp. 668-680.

Che, Yeon-Koo, Jinwoo Kim. 2006. Optimal collusion-proof auctions. Department of Economics Discussion Paper Series 0708-05, Columbia University.

Cho, In-Koo, Kevin Jewell, Rajiv Vohra. 2002. A simple model of coalitional bidding. *Economic Theory*, Vol. 19, pp. 435-57.

Cripps, Martin, Norman Ireland. 1994. The design of auctions and tenders with quality thresholds: the symmetric case. *The Economic Journal*, Vol. 104, pp. 316-326.

Estache, Antonio, Jose-Luis Guasch, Atsushi Iimi, Lourdes Trujillo. 2008. Multidimensionality and renegotiation: evidence from transport-sector public-private-partnership transactions in Latin America. Policy Research Working Paper No. 4665, the World Bank.

Estache, Antonio, Atsushi Iimi. 2008a. Procurement efficiency for infrastructure development and financial needs reassessed. Policy Research Working Paper No. 4662, the World Bank.

Estache, Antonio, Atsushi Iimi. 2008b. Joint bidding in infrastructure procurement. Policy Research Working Paper No. 4664, the World Bank.

Estache, Antonio, Atsushi Iimi. 2008c. Bidder asymmetry in infrastructure procurement: are there any fringe bidders? Policy Research Working Paper No. 4660, the World Bank.

Foster, Vivien. 2005. Ten years of water service reforms in Latin America: toward an Anglo-French model. Water Supply and Sanitation Sector Board Discussion Paper Series No. 3, The World Bank.

Gupta, Srabana. 2002. Competition and collusion in a government procurement auction market. *Atlantic Economic Journal*, Vol. 30, pp. 13-25.

Hendricks, Kenneth, Robert Porter. 1992. Joint bidding in federal OCS auctions. *American Economic Review*, Vol. 82, pp. 506-511.

Iimi, Atsushi. 2006. Auction reforms for effective official development assistance. *Review of Industrial Organization*, Vol. 28, pp. 109-128.

Klein, Michael. 1998. Bidding for concessions. Policy Research Working Paper Series No. 1957, The World Bank.

Krishna, Vijay, John Morgan. 1997. (Anti-)Competitive effects of joint bidding and bidder restrictions. Princeton Woodrow Wilson School Discussion Paper in Economics No. 184.

Levin, Dan, James Smith. 1994. Equilibrium in auctions with entry. *The American Economic Review*, Vol. 84, pp. 585-599.

Maddala, G.S. 1983. *Limited-Dependent and Qualitative Variables in Econometrics*. Cambridge University Press.

McAfee, Preston, John McMillan. 1987. Auctions with entry. *Economics Letters*, Vol. 23, pp. 343-347.

Menezes, Flavio, Paulo Monteiro. 2000. Auction with endogenous participation. *Review of Economic Design*, Vol. 5, pp. 71-89.

Moody, C.E., W.J. Kruvant. 1988. Joint bidding, entry and the price of OCS leases. *Rand Journal of Economics*, Vol. 19, pp. 276-284.

NOA. 2007. *Improving the PFI Tendering Process*. The National Audit Office.

Porter, Robert, Douglas Zona. 1993. Detection of bid rigging in procurement auctions. *Journal of Political Economy*, Vol. 101, pp. 518-538.

Porter, Robert, Douglas Zona. 1999. Ohio school milk markets: an analysis of bidding. *RAND Journal of Economics*, Vol. 30, pp. 263-288.

Price, Michael. 2008. Using the spatial distribution of bidders to detect collusion in the marketplace: evidence from timber auctions, *Journal of Regional Science*, Vol. 48, pp. 399-417.

Ware, Glenn, Shaun Moss, Edgardo Campos, Gregory Noone. 2007. Corruption in public procurement: a perennial challenge, in *The Many Faces of Corruption: Tracking Vulunerabilities at the Sector Level*, eds. by Edgardo Campos and Sanjay Pradhan, pp. 295-334. The World Bank.

Zellner, Arnold, H. Theil. 1962. Three stage least squares: simultaneous estimate of simultaneous equations, *Econometrica*, Vol. 30, pp. 54-78.