Productivity in Procurement Auctions of Pavement Contracts in Mexico

Daniel Prudencio[†]

January 12, 2022

Abstract

When allocating contracts, governments decide between exercising hiring discretion or allowing higher competition without firm selection. Ex-ante, it is not clear which allocation format leads to better outcomes. The trade-off depends in part on the government's ability to select the best firms when restricting competition and on the probability that this practice leads to corruption. In this paper, I study the allocation of street pavement contracts in Mexico. I combine auction methods with a productivity analysis to indirectly test whether local governments select firms with low excess costs when restricting competition. This indirect approach allows the monitoring of contract allocation in settings with little information on firm reputation. I find that firms selected to settings with less competition have lower costs in complex pavement contracts, but higher costs in simple ones. Contrary to the current practice, the results suggest that the government would benefit from using public auctions for simple pavement contracts.

Keywords: Procurement auctions, productivity, contract allocation, street pavement.

JEL Classification: L5, L88, L91, D22.

[†]Assistant Professor, Department of Economics, Tecnológico de Monterrey, Calle del Puente 222, Tlalpan, Mexico City, Mexico, PC 14380. Email: daprudencio@tec.mx. Orcid: 0000-0001-8290-3235. I am deeply indebted to Robin Sickles, Yunmi Kong and Rossella Calvi for their guidance and support. I owe special thanks to Isabelle Perrigne for many helpful comments and suggestions. I also thank Jeremy Fox, Mallesh Pai, Peter Schmidt, Hung-Jen Wang, Mahmoud El-Gamal, Katherine Ensor, James Brown, Pablo Gottret, Diego Escobari, Bruce Wydick, Phillip Ross, Maksat Abasov, Yessenia Tellez and faculty members and graduate students at Rice University for their comments and feedback. This work was supported by The Puentes Consortium. All errors are my own.

1 Introduction

When governments allocate a contract, they choose between allowing a large set of firms to compete for it or exercising greater hiring discretion to select the winning firm. Ex-ante, it is not clear which option leads to better outcomes. Allocation mechanisms that hamper competition may result in overpriced projects or corruption, and yet, greater discretion in selecting the winning firms could lead to improvements in the non-pecuniary characteristics of a project. The trade-off between these two allocation formats depends in part on the government's ability to select the best firms when restricting competition. Nevertheless, for developing countries specially, we know little about which firms are selected by the government when it exercises a greater hiring discretion. In a developing context, I use data from Mexico to study local governments' ability to select the firms with the lowest excess costs when choosing allocation mechanisms with less competition.

In Mexico, by law, the government should allocate public infrastructure contracts through the procedure that leads to lower construction costs. The law favors public procurement auctions (public auctions), but exceptions to the law allow the government to bypass this procedure and to either choose a firm of its preference (direct allocation) or conduct an auction by invitation to three or more firms (I3P). I leverage the variability in the different allocation mechanisms used for similar projects to study the government's firm selection when restricting competition.

In this paper, I focus on the allocation of street pavement contracts with hydraulic concrete from 2011 to 2018. I find that firms selected to settings with less competition are more experienced and have lower costs for complex pavement contracts (projects with sewage work). Nevertheless, for smaller and simpler projects, they have higher costs than firms that only participate in public auctions. A possible explanation is that the experienced firms are more competitive in complex projects due to economies of scope, where they leverage the cost complementarites of the different services they provide (sewage and pavement work). Alternatively, smaller and less experienced firms, consistent with product differentiation, may specialize in simpler projects where larger firms do not have a cost advantage when providing a single service. Overall, these results suggest that, for relatively small and simple projects, local governments would gain from increasing the use of public auctions. These results are in contrast to the actual practice, since 76 percent of pavement contracts allocated through auctions by invitation are small and simple[1].

When studying the influence of political factors on contract allocations, I find that local governments prefer allocation mechanisms with a greater hiring discretion during the year before municipal elections, where there is a six percent increase in the probability that the government will avoid

[1]Projects allocated through auctions by invitation are on average half the size of projects allocated though public auctions, and 76 percent of them do not include sewage work, compared to 62 percent in public auctions.

public auctions. As for the influence of political factors on the firms' average productivity, during the year before local elections, their average excess costs increased by 13.8 percent when participating in public auctions (compared to other public auction contracts in non-electoral times)[2]. Finally, when the municipality's mayor and state's governor belong to the same party, the firms' average excess costs decreased by 9.8 percent in public auctions. This increase in productivity may be due to a better coordination between local and state governments when political parties are aligned.

The above results come from the estimation of the firms' excess use of inputs, paired with information on the timing of contracts and elections. To approximate the firm's excess use of inputs, I follow a two-step procedure. First, I use the fact that most firms receiving contracts by direct allocation or auctions by invitation also participate in public procurement auctions. Therefore, I use a structural procurement auction model to analyze the public auction data and recover the firms' cost distribution. I model a first-price sealed bid auction under the independent value framework (IPV), controling for asymmetric bidders. The source of asymmetry between firms depends on whether a firm has received a project by direct allocation or I3P, or if it has only participated in public auctions[3]. On a second step, I augment the estimation of the pseudo costs with input data for street paving. Such data make it possible to use stochastic frontier analysis (SFA) to estimate a cost function allowing for differences in productivity levels between firms. These differences in productivity are captured by the firms' excess costs, estimated by the firms' excess use of inputs. To the best of my knowledge, this is one of the first papers that combines a structural auction model with SFA, where the firms' costs estimated from the auction model are used in the SFA. The potential for synergies between these two literatures is large. The auction methods allow the estimation of the often hard to get or estimate firms' costs, a key variable in SFA, which in turn can complement auction methods by providing more structure in analyzing efficiency differences between firms.

To test whether the government selects the firms with the lowest excess costs, I compare the estimates of the cost distributions and the firms' excess use of inputs to pave a street, of both the selected firms and those that only participate in public auctions. In developing countries, this

[2] Where the firms' productivity is defined as the proportion by which the firm overuses all inputs, given a fixed level of output and input prices.

[3] To recognize this source of asymmetry between firms is important. For example, if a firm's ability to win contracts is determined not by its productivity but by its ability to participate in settings with less competition, inefficient firms that would not have survived otherwise, may prevail in this market. On the other hand, if reputation matters, a productive firm with a proven record may be more likely to receive a project by direct allocation or to participate in auctions by invitation. In time, the experience gap would widen and generate productivity differences between the selected firms and firms that only participate in public auctions.

indirect approach to compare the firms' competitiveness is useful, as it allows us to circumvent the lack of publicly available information on the firms' reputation. To gather the auction bids and project characteristics, I construct a novel data set from the transcription and homogenization of close to 3000 public pavement contracts. Finally, to study the influence of political factors on the firms' excess use off inputs, I use the firms' cost profiles along with the timing of the pavement contracts and electoral data.

The rest of the paper proceeds as follows. I first discuss the related literature in the remainder of the introduction. Section 2 discusses the allocation procedure of street pavement contracts, along with a description of the bid data. Section 3 describes the procurement auction model and the SFA, followed by a discussion of the results in Section 4. Section 5 concludes.

Related Literature

The present paper is related to several strands of literature. First, it is related to auction models with asymmetric bidders[4]. A difficulty in estimating these types of models is the lack of closed-form solutions, hence, early papers rely on numerical methods as proposed by Bajari (2001). Nevertheless, recent developments in non-parametric identification have made the estimation of these models more accessible[5]. The majority of asymmetric auctions applications emerge from the extension of Guerre, Perrigne, and Vuong (2000) to various settings. For example, Flambard and Perrigne (2006) propose a nonparametric procedure in the framework of independent private value (IPV) with a binding reserve price, whereas Marion (2007) estimates a model under a preference policy that favors smaller firms. Other extensions include the consideration of unobserved heterogeneity by Krasnokutskaya (2011) and Hu, McAdams, and Shum (2013), endogenous entry by Krasnokutskaya and Seim (2011), unobserved bidder's identity by Lamy (2012) and sequential auctions by Jofre-Bonet and Pesendorfer (2003). Under the framework of affiliated private value (APV), Campo, Perrigne, and Vuong (2003) and Zhang and Guler (2005) also provide nonparametric estimators. This paper contributes to this literature in two ways. First, by considering a new source of asymmetry between firms: the difference in experience and resources due to the government's selection of certain firms to settings with less competition. Second, by combining auction methods with a stochastic frontier analysis to further study productivity differences among firms.

A second related literature compares project allocation mechanisms. The comparison of public auctions to other mechanisms has grown since early work by Bulow and Klemperer (1996, 2009), which stresses the benefits of competition in a simultaneous auction, relative to any other mech-

[4]See Maskin and Riley (2000); Maskin, Eric and Riley, John (2000) for theoretical results.

[5]See Hickman, Hubbard, and Sağlam (2012) and Perrigne and Vuong (2019) for surveys on the econometrics of first-price bid auction models.

anisms with less competition. Nevertheless, recent research has shown that an auction might not be the preferred allocation procedure for every setting. For example, Roberts and Sweeting (2013) show that when comparing a simultaneous auction with a sequential negotiation, if the entry to the negotiation is costly and selective, sellers with higher values are more likely to participate in the negotiation. Thus, the revenue performance between the two mechanisms depends on whether the threat of potential future competition in a negotiation is more valuable to the seller than the actual competition of an auction. Other authors, such as Bajari and Tadelis (2001), Bajari, McMillan, and Tadelis (2009), Baldi, Bottasso, Conti, and Piccardo (2016), and Herweg and Schmidt (2017) note that a negotiation procedure might be preferred over an auction if the good is complex, or as in Bajari, Houghton, and Tadelis (2014), if the contractual design is incomplete. The key insight of this literature is that negotiations might be preferred when there are gains from the early exchange of information, so that the probability of ex-post adaptations is minimized. Relatedly, when negotiations are not possible, Spagnolo (2012) argues that it might be optimal to give the seller more discretion to select who can participate in an auction. Although the probability of corruption increases and competition is hampered, a good selection of firms may improve non-contractable aspects of the work, such as quality. In line with this research, Calzolari and Spagnolo (2010) argue that competitive screening might be optimal when non-contractable dimensions are important. In this case, the reputation of the firms can be a good discriminatory variable, as shown by Banerjee and Duflo (2000). Recent papers have empirically tested the effect of discretion on procurement outcomes. For the case Italy, Coviello, Guglielmo, and Spagnolo (2018) and Decarolis, Fisman, Pinotti, and Vannutelli (2021) find that, in general, greater discretion improves efficiency at the expense of a relatively low increase in corruption. Consistent with these results, for the case of US federal procurement, Carril (2021) finds that rules restricting discretion leade to modest waste prevention relative to the costs introduced by regulation. Nevertheless, for the case of Hungary, Szucs (2020) finds that discretion leads to increases in prices and corruption. This paper contributes to this literature by providing an empirical test on whether the government selects the best firms in terms of costs when restricting competition. That is, I test whether local governments select firms with the lowest excess costs when opting for mechanisms with more discretion in the selection of the competing firms. This test is performed in a developing context, Mexico, and the auctionable object is relatively small and homogeneous, hence, cost efficiency is of concern.

Finally, this paper is also related to the stochastic frontier analysis literature, which uses econometric models to estimate the cost frontier. A measurement of the firms' relative excess use of inputs is, then, the extent to which the firms fail to reach the cost frontier. The study of SFA has a long history. For recent surveys see Greene (2008), Behr (2015), Kumbhakar, Wang, and Horncastle (2015) and Sickles and Zelenyuk (2019). As noted above, a contribution of this paper is the combination of auction methods and SFA. Recent developments in structural econometric methods for the study of auctions in the last two decades allow the estimation of the firms' cost distribution. The use of the estimated or pseudo cost can be greatly beneficial to SFA, since we often do not observe the firms' production costs, a key variable in SFA.

2 Public Construction Contracts in Mexico

This section describes the data on public construction contracts for street pavement with hydraulic concrete, first explaining the allocation procedure for a pavement contract, followed by a description of the bid data for the period 2011 to 2018.

2.1 Context on the Procurement Auction Procedure

To control the use of public funds when allocating infrastructure contracts, the Mexican government should use the allocation procedure that leads to lower costs. Even though the law favors the use of public auctions, when the construction project is relatively small, the law provides exceptions that enable the government to bypass the public auction either by assigning a project directly to a preferred firm or by inviting three or more firms to an auction. The latter procedure is denoted as I3P. The exceptions that allow the government to bypass a public procurement auction are detailed in the Law of Public Works and Related Services (LPWRS). Some exceptions are vague and broad, and allow for an undue degree of discretion in assigning public works contracts.

The data from public procurement auctions are stored in an online system called CompraNet, which is the government's electronic public information system for acquisitions, leases, and for the allocation of public works and related services. This system is overseen by the Secretariat of Public Function, through the Public Procurement Policy Unit (UPCP). Through CompraNet, the procedures and data from previous contracts are publicly available. Moreover, CompraNet is not only an entity that centralizes government contract information, but also the system through which the government conducts some of its auctions and procurements.

According to the "Law of Public Works and Related Services", the government should favor the use of a public auction to allocate a construction contract. If this is not possible, it should use an auction by invitation or direct allocation. The exceptions that allow the government to bypass a public auction can be found in the third chapter of the law, article 41. The most important exceptions regarding public construction projects are as follows:

- There are circumstances that could cause significant losses or additional costs, duly justified.

- Due to major forces, it is not possible to execute the work by means of the public tender procedure within the time required to attend to the eventuality in question.
- The respective contract has been rescinded for reasons imputable to the contractor. In this case, the second best offer wins the contract.
- No one attends to the public auction.
- Maintenance, restoration, reparation, or demolition services are required.
- Rural labor is required, or the project is in a marginalized urban area.

Under the legal umbrella of these exceptions, state and federal governments can choose contractors without a public procurement auction. Only one of this exceptions needs to apply for the government to be able to bypass a public auction. The first two exceptions are of special concern because of their vague terms. In the current study, I do not consider contracts of maintenance, restoration, reparation, or demolition, and I have found little evidence of the third and fourth exceptions, which are directly observable from the data. Hence, I am assume that the choice of a direct allocation procedure or auction by invitation is mainly due to the first two exceptions. If none of these exceptions apply, the procurement auction procedure used is a public first-price sealed bid auction.

2.2 Bid Data: Public Procurement Auctions

From 2011 to 2018, I observe 3698 contracts for the pavement of small streets with hydraulic concrete. Of these, 2633 were allocated through I3P, 448 by direct allocation, and 617 by public procurement auction[6]. Here I focus on the public procurement auction data. Of these 617 contracts, the government does not disclose the project characteristics of 213 of these 617 contracts, leaving a sample of 404 procurement auctions with 2,784 observed bids. Table 1 provides the summary statistics of the bids. The average bid per cubic meter is 9.01 thousand Mexican pesos per cubic meter of concrete at 2018 prices, with large standard deviation of around 7.57. Surprisingly, the average winning bid is close to but above the average price. Part of this difference is explained by the fact that many low bids are rejected because they were not presented with the required format,

[6]The small number of contracts is driven by several factors. First, I am using a specific technology for paving, mainly, pavement with hydraulic concrete, which serves to reduce heterogeneity in the technology used for a specific project. Second, I do not consider all maintenance contracts, since they are usually directly allocated to the firm that first received the project. Finally, I am focusing on the paving of small streets, without considering the pavement of avenues, interstate or federal projects. This last restriction, along with the restriction in the technology used, makes the auctionable projects much more homogeneous.

or the contract was missing information ($\sim 23\%$). But even when accounting for these factors, a small gap remains.

The average number of bidders in a public auction is close to seven. In each public auction, approximately two bidders received at some point a pavement contract by direct allocation or have been invited to participate in an auction of three or more firms. Likewise, on average, there are close to five bidders per auction that have only participated in public auctions. As for the project characteristics, the average contract used 730.8 cubic meters of concrete and lasted around 3.44 months[7]. As observed by the standard deviation of both of these variables, even though only contracts for small streets (as opposed to avenues and highways) are considered, a large variability in the size of the streets paved can still be noted. The observed project heterogeneity, as well as the competition between firms, may be the driving forces behind the bid heterogeneity.

Table 1: Summary statistics, first-price sealed bid auctions

	Mean	Median	S.D.	Min	Max	Obs
Bids/m^3 concrete (thousands per m^3)	9.01	7.13	7.57	0.87	92.6	2784
Winning bid/m^3 concrete	9.40	7.45	7.49	1.31	62.1	404
Number of bidders: total	6.89	5	6.22	1	35	404
Num. bidders: at some point Direct/I3P	2.03	2	2.15	0	15	404
Num. bidders: only Public Auction	4.86	3	5.24	0	35	404
M^3 concrete	730.8	588.4	574.9	23.5	4072.9	404
Dummy = 1 if proj. includes sewage work	0.38	0	0.49	0	1	404
Duration of project (months)	3.44	3	3.91	0	49	404
Dummy = 1 if municipal project	0.84	1	0.36	0	1	404

Note: public auction data.

I next study the evidence of asymmetry between firms that have been approached by the government to participate in a format with less competition (i.e., they have received a project by direct allocation or been invited to an auction), compared to firms that only participated in public auctions. For public auctions with the same proportion of these two types of firms, the firms that have been approached by the government won 56 percent of the time, although this is proportion not significantly different from 50 percent. When looking at the experience of these two types of firms, important contrasts can be seen. For example, again for the auctions with the same proportion of these types of bidders, the firms approached by the government represented

[7] The average project paves eight to nine blocks that are each 50 meters long.

70 percent of the firms with an overlapping project. Furthermore, during the studied period, they had competed in 4.5 different public auctions on average, compared to only 3.39 for the firms that were never approached by the government. The experience gap is wider when also accounting for the contracts under all the allocation mechanisms. In the full data set, the firms approached by the government competed for 6.63 contracts, while firms that only took part in public auctions participated in just 3.35 contracts on average. These differences in experience are also reflected also in gaps in the proportion of firms that have been rejected due to procedural issues.

To further explore the asymmetry between bidders, I perform a Chow-test of equality of coefficients, which consists of regressing the logarithm of the bids on a set of project characteristics[8], and comparing whether the causal relationship varies by the type of the firm. Hence, of the 2,784 bids, I run separate regressions for the 1,962 bids submitted by the firms approached by the government, and for the 822 bids submitted by the firms that only participated in public auctions. The Chow-test strongly rejects the equality of parameters of these two regressions. Finally, I compare the conditional bid densities for both types of firms controlling for the total volume of concrete. I perform a Kolgomorov-Smirnov test when evaluating the conditional densities at the 25th, 50th and 75th percentile of the amount of concrete, rejecting the null that the bids of each type of firm are drawn from the same distribution when the densities are evaluated at the 25th and 75th percentile, although I fail to reject when evaluating the densities at the 50th percentile of the total amount of concrete. For a display of the conditional cdfs, see Figure 3 in the Appendix.

Finally, I analyze the bid variability, and further study the determinants of the government's choice of allocation procedure, by looking at the correlation between firm and project characteristics with the level of the bids, and the choice of allocation mechanism. To assess the variability of the bids, I present a reduced-form analysis where I regress the log of the bids on a set of firm and project characteristics. The results are found in Table 2.

Although not shown, the project characteristics included in the regression are a dummy variable if the specification of the project is highly detailed, such as the number of signs, trees, posts, amount of paint, whether the project includes sewage work, whether it includes work on the potable water system, and whether the contract was allocated by the municipal government (and not by the state government). When comparing the bids, firms that participated in an auction by invitation or received a project by direct allocation, bid on average 8.5 percent higher than firms that only

[8] I control for the bidder's experience, the number of firms per auction, duration of the project, a dummy variable if it is a municipality project and a set of year dummies.

participate in public auctions. The number of bidders, as expected, has a negative effect on the bids, which favors the independent value framework (IPV) when modeling the auction. This result is consistent with Hong and Shum (2002) who also studied road construction auctions, and found that the common value framework is more fitting for larger projects, whereas the IPV framework seems to be appropriate for smaller ones, like the projects studied here. The firm's experience, measured by the number of projects for which the firm competed from 2011 to 2018, lowers the level of the bid. Bids are higher for projects that take longer to complete, and although the difference is marginal, it may show that projects which take longer are more complex.

Table 2: OLS: dependent variable = log(bids/m^3)

	Coef.	S.E.
Dummy = 1 if any Direct or I3P[1]	0.0856***	(0.0211)
Firm's experience[2]	-0.0104***	(0.0021)
Number of bidders	-0.0111***	(0.0013)
Duration of project (months)	0.0115**	(0.0050)
Observations	2,784	
L	404	
R-squared	0.336	
Municipality FE	No	
Year FE	Yes	
Proj characteristics	Yes	

Standard deviations in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Data: public auctions. Other project characteristics included are: a dummy variable if the specification of the project is highly detailed, the number of signs, trees, posts, and amount of paint, whether the project includes work on the sewage and potable water systems.
[1]I3P = auctions by invitation to three or more firms.
[2]The firm's experience denotes the number of auctions in which it participated.

Political influence on the mechanism choice

To study the choice of mechanism, I investigate the correlation between the choice of allocation procedure with political factors, and with firm and project characteristics. Hence, I estimate a probit, where the dependent variable is equal to one if the allocation format is by direct allocation or auction by invitation, and zero if it is by public auction.

First, when looking at the project characteristics, the bigger the project, the more likely it will be allocated by public auction. For example, an increase of one standard deviation in the cubic meters of concrete would lead to an 11.4 percent decrease in the probability that the mechanism chosen will be by direct allocation or auction by invitation. Likewise, if the project includes sewage work, there is a 9.8 higher probability that it will be allocated through a public auction. In other words, smaller and simpler projects are allocated through mechanisms with less competition.

Table 3: Probit: dependent variable, dummy = 1 if Direct or Auction by Invitation (I3P), dummy = 0 if by Public Auction.

	Marginal Effects	S.E.
M^3 concrete (hundreds)	-0.0002***	(2.43e-05)
Dummy = 1: includes sewage work	-0.093***	(0.023)
Duration of project (months)	-0.002	(0.002)
Dummy = 1: if one year before elections	0.062***	(0.022)
Dummy = 1: political party PAN[1]	-0.189***	(0.036)
Dummy = 1: political party PRD[1]	-0.033	(0.038)
Dummy = 1: other small political parties[1]	-0.012	(0.027)
Dummy = 1: Mun. and Gov. from the same party	-0.005	(0.027)
Total number of contracts in municipality	-1.54e-06	(6.07e-05)
Fund FISE (millions)[2]	3.76e-04***	(4.85e-05)
Pseudo R2	0.218	
Observations	1,707	
Proj. characteristics	Yes	

Standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Data: contract winners. The sample uses all allocation procedures. Other project characteristics included are: the number of signs, trees and posts to be installed, and the surface to be painted. Additionally, I control for: the bidder's experience, whether the bidder has an overlapping project, the amount of precipitation in the municipality, and a construction price index.

[1]During the sample period, the main political parties were the PRI, PAN, and PRD. The incumbent party PRI is left out.

[2]FISE is a state fund for social construction purposes.

When looking at political factors, the government chooses allocation mechanisms with a greater hiring discretion during the year before elections, where the probability of avoiding a public auction increases by 6.2 percent. This result is consistent with Abbott, Cabral, and Jones (2017), who study the strategic allocation of funds in times of elections. Two possible causes are corruption, where the government favors certain firms in exchange for support, and second, the need to speed up the allocation of contracts during electoral times. Nevertheless, I cannot empirically test for these. I then look at how the choice of allocation procedure differs by political party. From 2011 to 2018, the main political parties were the PRI (the incumbent center-left party), PAN (the center-right main opposition party), and PRD (the left-leaning opposition party). Compared to the incumbent PRI, when the political party PAN was in office, the contractual office was 18.9 percent less likely to use direct allocations or auction by invitation. When the PRD or other minor parties were in office, the contractual office was equally likely to use these procedures in the same way as the contractual offices under the PRI. Finally, I look at the characteristics of the state or municipality that may influence the choice of mechanism, considering three variables: the total number of contracts in a municipality, a state fund for social construction purposes denominated FISE, and, finally, whether the project was given by a municipality. We would expect that a high volume of contracts would induce the government to prefer faster allocation mechanisms, avoiding public auctions, but the volume of contracts does not seem to influence the choice of procedure[9].

The reduced-form analysis of the bids is insightful and informative. Nevertheless, it does not allow us to assess the differences in the cost distributions between firms that are selected by the government to participate in settings with less competition, and firms that only participate in public auctions. The structural approach that follows addresses this question.

3 Structural Analysis of Procurement Auctions

3.1 Procurement Auction Model with Asymmetric Bidders

The format used by the government is a first-price sealed-bid procurement auction with a random reserve price, which means that the reserve price is not announced ex-ante. For the projects studied here, it is not reported ex-post either[10]. Nevertheless, the contract information makes it possible

[9] Although not included in the regression, there is little variability in the use of format by the population size of the municipality. The biggest cities allocate 18% of their street pavement contracts through public auctions, and the other cities have a corresponding percentage of 16%.

[10] Based on information from the project contracts, the government only reports the reserve price ex-post for three percent of the sample.

to asses how binding the reserve price is because the bidder is informed if the submitted bid was above it. In the full data set, I find the the reserve price is binding only in two percent of the data, so I model the auction without it[11].

Given the evidence of the negative effect of competition on the level of the bids, and Hong and Shum (2002)'s results, I model the auction under an IPV framework with asymmetric bidders[12]. The model is hence based on Flambard and Perrigne (2006) (FP), but without a reserve price. Let n be the number of risk neutral bidders. Each bidder i can be of type 1 (bidders that, at some point, have either received a project by direct allocation or have been invited to participate in an auction) or type 0 (bidders that have only participated in a public auction), such that $n_0 + n_1 = n$. Let c_{ji}, for $i = 1, ..., n_j$ denote the cost of bidder of type $j \in \{0, 1\}$. The costs c_{1i} and c_{0i} are drawn from $F_1(\cdot)$ and $F_0(\cdot)$ respectively, defined on $[\underline{c}, \bar{c}]$. Let $f_0(\cdot)$ and $f_1(\cdot)$ be the continuous and differentiable cost densities with $f_1(\cdot) > 0$ and $f_0(\cdot) > 0$. Finally, the information set of bidder i of type j is $[c_{ji}, F_0(\cdot), F_1(\cdot), n_0, n_1]$.

At a Bayesian Nash Equilibrium, each bidder i of type 1 chooses his bid b_{1i} to maximize his expected profit $E[(b_{1i} - c_{1i})\mathbb{1}(b_{1i} \leq B_{1i})]$, where $B_{1i} = min[s_0(C_0), s_1(C_{1i})]$, $C_0 = min_i c_{0i}$ and $C_{1i} = min_{j \neq i} c_{1i}$, and $s_0(\cdot)$ and $s_1(\cdot)$ are the strictly increasing equilibrium strategies for types 0 and 1, respectively. Then, bidder i of type 1 chooses his bid b_{1i} that maximizes his expected profit:

$$(b_{1i} - c_{1i})\Pr[s_1^{-1}(b_{1i}) \leq C_{1i} \text{ and } s_0^{-1}(b_{1i}) \leq C_0],$$

or equivalently, it maximizes:

$$(b_{1i} - c_{1i})\{1 - F_1[s_1^{-1}(b_{1i})]\}^{n_1 - 1}\{1 - F_0[s_0^{-1}(b_{1i})]\}^{n_0}.$$

The bid b_{0i} is defined similarly for an individual i of type 0. Following Guerre et al. (2000) (GPV), differentiating the expected profit for firms of type 1 and type 0 with respect to b_{1i} and b_{0i} respectively, leaving the following system of equations. For $i = 1, ..., n_1$, we have:

$$(b_{1i} - c_{1i})\left\{(n_1 - 1)\frac{f_1[s_1^{-1}(b_{1i})]}{1 - F_1[s_1^{-1}(b_{1i})]}\frac{1}{s_i'[s_1^{-1}(b_{1i})]} + n_0\frac{f_0[s_0^{-1}(b_{1i})]}{1 - F_0[s_0^{-1}(b_{1i})]}\frac{1}{s_0'[s_0^{-1}(b_{1i})]}\right\} = 1. \quad (1)$$

[11]For a model specification with random reserve price see Elyakime, Laffont, Loisel, and Vuong (1994, 1997) and Li and Perrigne (2003). An application for asymmetric bidders with a random reserve price follows directly by combining the models of Li and Perrigne (2003) and Flambard and Perrigne (2006).

[12]Notice that I do not consider an entry cost, this is mainly for two reasons: the use of a random reserve price, and because the auctioned object, is a small homogeneous object for construction (pavement of small streets), built with a specific technology (hydraulic concrete).

Similarly, for $i = 1, ..., n_0$ we have:

$$(b_{0i} - c_{0i})\left\{(n_1)\frac{f_1[s_1^{-1}(b_{0i})]}{1 - F_1[s_1^{-1}(b_{0i})]}\frac{1}{s_i'[s_1^{-1}(b_{0i})]} + (n_0 - 1)\frac{f_0[s_0^{-1}(b_{0i})]}{1 - F_0[s_0^{-1}(b_{0i})]}\frac{1}{s_0'[s_0^{-1}(b_{0i})]}\right\} = 1. \quad (2)$$

The above system of equations does not have a closed form solution, but the results in Flambard and Perrigne (2006) allow to solve this problem by extending the indirect approach of GPV for asymmetric bidders. The indirect approach starts from the differential equations (1) and (2), and uses the fact that while the costs are not observed, the bids are, and the equilibrium strategies relate the former to the latter. Flambard and Perrigne (2006) use the monotonicity of the strategy functions to relate the cost and bid distributions. Let $G_j(\cdot)$ denote the bid CDF o the type j bidder. FP note that $G_j(\cdot) = F_j[s^{-1}(\cdot)]$, for $j = 0, 1$. In other words, the indirect approach uses the observed bid distribution to estimate the cost distribution, with the advantage that it avoids making parametric assumptions about $F_j(\cdot)$ or computing the equilibrium strategies $s_j(\cdot)$.

Identification and Estimation

As is standard in structural estimation, the observed bids are assumed to be the equilibrium outcomes. Given the above results, the model is given by $b_{1i} = s_1(c_{1i}, F_1, F_0, n_1, n_0)$, $i = 1, ..., n_1$ and $b_{0i} = s_0(c_{0i}, F_1, F_0, n_1, n_0)$, $i = 1, ..., n_0$. The primitives of the model are $n_1, n_0, F_1(\cdot)$, and $F_0(\cdot)$, and the observables are n_0, n_1 and the bid distributions $G_0(\cdot|n_1, n_0)$ and $G_1(\cdot|n_1, n_0)$. Because of the one-to-one mapping at the equilibrium, the authors use the equalities $G_1(b_{1i}) = F_1(s_1^{-1}(b_{1i}))$, $G_0(b_{0i}) = F_0(s_0^{-1}(b_{0i}))$, $g_1(b_{1i}) = f_1(s_1^{-1}(b_{1i}))/\ \{s_1'(s_1^{-1}(b_{1i}))\}$, and $g_0(b_{0i}) = f_0(s_0^{-1}(b_{0i}))/\{s_0'(s_0^{-1}(b_{0i}))\}$ to rewrite the system of differential equations (1) and (2) as:

$$\begin{aligned} c_{1i} &= b_{1i} - \frac{1}{(n_1 - 1)\frac{g_1(b_{1i}|n_1,n_0)}{1-G_1(b_{1i}|n_1,n_0)} + (n_0)\frac{g_0(b_{1i}|n_1,n_0)}{1-G_0(b_{1i}|n_1,n_0)}}, \\ &\equiv \xi_1[b_{1i}, G_0(\cdot|n_1, n_0), G_1(\cdot|n_1, n_0), n_1, n_0], \end{aligned} \quad (3)$$

$$\begin{aligned} c_{0i} &= b_{0i} - \frac{1}{(n_1)\frac{g_1(b_{0i}|n_1,n_0)}{1-G_1(b_{0i}|n_1,n_0)} + (n_0 - 1)\frac{g_0(b_{0i}|n_1,n_0)}{1-G_0(b_{0i}|n_1,n_0)}}, \\ &\equiv \xi_0[b_{0i}, G_0(\cdot|n_1, n_0), G_1(\cdot|n_1, n_0), n_1, n_0]. \end{aligned} \quad (4)$$

Given that we can observe $g_j(\cdot)$ and $G_j(\cdot)$ for $j \in \{0, 1\}$, we identify the costs of each firm. A practical advantage of this identification approach is that it also gives us the estimation method. For estimation, consider L auctions indexed by $\ell = 1, ..., L$. Let $\mathbf{z}_\ell$ be a vector of covariates that characterize the auctioned object ℓ, observed by the econometrician. We observe $\{b_{1p\ell}, p = 1, ..., n_{1\ell}, b_{0q\ell}, q = 1, ..., n_{0\ell}, \mathbf{z}_\ell, \ell = 1, ..., L\}$. The model is conditional on $\mathbf{z}_\ell$ and the number of bidders $n_{1\ell}$ and $n_{0\ell}$. Equations (3) and (4) suggest that the first step is to estimate the ratios $g_j(\cdot)/(1 - G_j(\cdot))$ for $j = 0, 1$. I use then kernel estimators for the cumulative distribution and density functions, given by:

$$\hat{G}_1(b|\mathbf{z}, n_1, n_0) = \frac{\sum_{\ell=1, n_{1\ell}=n_1, n_{0\ell}=n_0}^{L} \frac{1}{n_1} \sum_{p=1}^{n_1} \mathbb{1}(b_{1pl} \leq b) K_G\left(\frac{\mathbf{z}-\mathbf{z}_l}{h_{zG}}\right)}{\sum_{l=\ell=1, n_{1\ell}=n_1, n_{0\ell}=n_0}^{L} K_z\left(\frac{\mathbf{z}-\mathbf{z}_l}{h_{zG}}\right)},$$

$$\hat{G}_0(b|\mathbf{z}, n_1, n_0) = \frac{\sum_{\ell=1, n_{1\ell}=n_1, n_{0\ell}=n_0}^{L} \frac{1}{n_0} \sum_{q=1}^{n_0} \mathbb{1}(b_{0ql} \leq b) K_G\left(\frac{\mathbf{z}-\mathbf{z}_l}{h_{0G}}\right)}{\sum_{l=\ell=1, n_{1\ell}=n_1, n_{0\ell}=n_0}^{L} K_z\left(\frac{\mathbf{z}-\mathbf{z}_l}{h_{zG}}\right)},$$

$$\hat{g}_1(b|\mathbf{z}, n_1, n_0) = \frac{\frac{1}{h_{1g}} \sum_{l=1}^{L} \frac{1}{n_1} \sum_{p=1}^{n_1} K_g\left(\frac{b-b_{1pl}}{h_{1g}}, \frac{\mathbf{z}-\mathbf{z}_l}{h_{zg}}\right)}{\sum_{l=\ell=1, n_{1\ell}=n_1, n_{0\ell}=n_0}^{L} K_z\left(\frac{\mathbf{z}-\mathbf{z}_l}{h_{zg}}\right)},$$

$$\hat{g}_0(b|\mathbf{z}, n_1, n_0) = \frac{\frac{1}{h_{0g}} \sum_{l=1}^{L} \frac{1}{n_0} \sum_{q=1}^{n_0} K_g\left(\frac{b-b_{0ql}}{h_{0g}}, \frac{\mathbf{z}-\mathbf{z}_l}{h_{0g}}\right)}{\sum_{l=\ell=1, n_{1\ell}=n_1, n_{0\ell}=n_0}^{L} K_z\left(\frac{\mathbf{z}-\mathbf{z}_l}{h_{zg}}\right)},$$

where $K_G(\cdot)$ and $K_g(\cdot)$ represent kernel estimators, and h_{zG}, h_{zg}, h_{1g}, and h_{0g} some bandwidths, following the bandwidth selection procedure in FP. Then, in a second step, I use the equilibrium bids, the estimated conditional bid distributions $\hat{G}_1(\cdot|\mathbf{z}_\ell, n_1, n_0)$, $\hat{G}_0(\cdot|\mathbf{z}_\ell, n_1, n_0)$, along with their respective density functions, to estimate the pseudo costs by,

$$\hat{c}_{1p\ell} = b_{1p\ell} - \frac{1}{(n_1 - 1)\frac{\hat{g}_1(b_{1p\ell}|\mathbf{z}_\ell, n_1, n_0)}{1-\hat{G}_1(b_{1p\ell}|\mathbf{z}_\ell, n_1, n_0)} + n_0 \frac{\hat{g}_0(b_{1p\ell}|\mathbf{z}_\ell, n_1, n_0)}{1-\hat{G}_0(b_{1p\ell}|\mathbf{z}_\ell, n_1, n_0)}}, \tag{5}$$

$$\hat{c}_{0q\ell} = b_{0q\ell} - \frac{1}{(n_1)\frac{\hat{g}_1(b_{0q\ell}|\mathbf{z}_\ell, n_1, n_0)}{1-\hat{G}_1(b_{0q\ell}|\mathbf{z}_\ell, n_1, n_0)} + (n_0 - 1) \frac{\hat{g}_0(b_{0q\ell}|\mathbf{z}_\ell, n_1, n_0)}{1-\hat{G}_0(b_{0q\ell}|\mathbf{z}_\ell, n_1, n_0)}}. \tag{6}$$

A well known problem of kernel density estimators is that they do not behave well at the boundaries of their support. This problem can be dealt with some trimming[13]. Then, in a third step, using the estimates $\{\hat{c}_{1p\ell}, \hat{c}_{1q\ell}, p = 1, ..., n_{1\ell}, q = 1, ..., n_{0\ell}, \ell = 1, ..., L\}$ of the sample after

[13] Other methods for dealing with this problem include using bias-corrected kernel estimators, as proposed by Hickman and Hubbard (2015).

trimming, I estimate the conditional densities $f_1(\cdot|\mathbf{z}_\ell)$ and $f_0(\cdot|\mathbf{z}_\ell)$ by,

$$\hat{f}_1(c, \mathbf{z}, n_1, n_0) = \frac{\frac{1}{h_{1f}} \sum_{\ell=1, n_{1\ell}=n_1, n_{0\ell}=n_0}^{L} \frac{1}{n_1} \sum_{p=1}^{n_1} K_g\left(\frac{c-\hat{c}_{1pl}}{h_{1f}}, \frac{\mathbf{z}-\mathbf{z}_l}{h_{zf}}\right)}{\sum_{l=\ell=1, n_{1\ell}=n_1, n_{0\ell}=n_0}^{L} K_z\left(\frac{\mathbf{z}-\mathbf{z}_l}{h_{zg}}\right)}, \tag{7}$$

$$\hat{f}_0(c, \mathbf{z}, n_1, n_0) = \frac{\frac{1}{h_{0f}} \sum_{\ell=1, n_{1\ell}=n_1, n_{0\ell}=n_0}^{L} \frac{1}{n_0} \sum_{q=1}^{n_0} K_g\left(\frac{c-\hat{c}_{0ql}}{h_{0f}}, \frac{\mathbf{z}-\mathbf{z}_l}{h_{zf}}\right)}{\sum_{l=\ell=1, n_{1\ell}=n_1, n_{0\ell}=n_0}^{L} K_z\left(\frac{\mathbf{z}-\mathbf{z}_l}{h_{zg}}\right)}, \tag{8}$$

where $K(\cdot, \cdot)$ denotes the product of kernels, and h_{1f}, h_{0f} and h_{zf} some optimal weights. The comparison of $\hat{\xi}_1(\cdot)$ and $\hat{\xi}_0(\cdot)$, and of $\hat{f}_1(\cdot|\cdot)$ and $\hat{f}_0(\cdot|\cdot)$, informs us about the presence of asymmetry and cost differences between the two types of firms.

Practical Issues in Estimation

Given the curse of dimensionality in nonparametric conditional density estimators, I reduce the dimension of $\mathbf{z}_\ell$ to two, the cubic meters of concrete, to proxy for the size of the project, and a dummy for whether the project includes sewage work, to proxy for the complexity of the project[14]. I use a triweight-Kernel for the the cubic meters of concrete, as well as for the costs when estimating the cost function. For the dummy variable, I use the Kernel proposed by Aitchison and Aitken (1976) to smooth a binary variable. Notice also that when considering asymmetric bidders, the data requirements are greater than in the symmetric case. Hence, instead of conditioning the density estimators on specific values of n_1 and n_0, I stratify the sample according to two categories of the number of bidders of each type, similar to Hendricks, Pinkse, and Porter (2003) and Luo, Perrigne, and Vuong (2016). Hence, I consider four sub-samples of auctions, the first with low levels of competition of both types of bidders, $n_1 \leq 3$ and $n_0 \leq 3$ (subject to $n_1 + n_0 \geq 2$), two sub-samples with mixed levels of competition, and finally, the case with high levels of competition for both types of bidders with more than three bidders of each type. Finally, a known problem of the bid's distribution is that it tends to be skewed. Therefore, as in Marion (2007), I use a logarithmic transformation of the data to minimize this effect. Equations (5) and (6) are re-written

[14] Haile, Hong, and Shum (2003) suggest an alternative way to deal with the multimensionality of $\mathbf{z}_\ell$. The authors suggest to estimate the auction model using the residuals of the regression of the level of bids on a set of project characteristics, and then to adjust the estimation of $\hat{c}$ accordingly. I followed this approach for a robustness analysis and the results do not change. Results are available upon request.

as:

$$\hat{c}_{1i} = \exp(a) - \frac{\exp(a)}{(n_1 - 1)\frac{\hat{g}_{1a}(a)}{1-\hat{G}_{1a}(a)} + (n_0)\frac{\hat{g}_{0a}(a)}{1-\hat{G}_{0a}(a)}} - 1, \tag{9}$$

$$\hat{c}_{0i} = \exp(a) - \frac{\exp(a)}{(n_1)\frac{\hat{g}_{1a}(a)}{1-\hat{G}_{a1}(a)} + (n_0 - 1)\frac{\hat{g}_{0a}(a)}{1-\hat{G}_{0a}(a)}} - 1, \tag{10}$$

where $a \equiv log(1+b)$, $\hat{G}_{ja}(\cdot)$ and $\hat{g}_{ja}(\cdot)$ are the corresponding estimated cumulative distribution and density functions of $\log(1+b)$ for $j = 0, 1$.

3.2 Firms' Excess Cost Analysis

The objective of this sub-section is to use a stochastic frontier analysis (SFA) to estimate the firms' excess use of inputs, which, all else equal, would translate into excess costs. The SFA is an econometric approach that estimates the cost frontier, and measures the firms' excess use of inputs as the distance between the firms' efficiency to the cost frontier. Provided that a firm is inside the cost frontier at an inefficient point, it can reach the frontier in at least two ways. First, by reducing the level of inputs conditional on a level of output. The extent to which the firm can reduce the level of inputs is known as the firm's technical inefficiency. Secondly, it can reach the frontier by increasing the level of output conditional on a level of inputs. The extent to which this can be done is known as the firm's allocation inefficiency. Since the level of output is exogenously set by the government in street pavement contracts, I focus on the firms' technical inefficiency.

Under the SFA framework[15], the idiosyncratic error plays a key role when approximating the cost function[16]. The error has typically two components, one is the usual disturbance that represents latent factors such as measurement error, misspecification of the model or inherent randomness of the production process. The second is a latent variable that represents the excess costs. This additional component is restricted to having positive values, and is specific to each firm i, denoted by η_i.

A key variable in SFA is the cost of production, which is hard to obtain or approximate. A contribution of this paper is the use of auction methods as a first step to estimate the firms' costs, and then expand the analysis using tools from SFA. Given the long history of the SFA's literature,

[15]For recent reviews of the SFA literature, see Greene (2008), Kumbhakar et al. (2015), and Sickles and Zelenyuk (2019).

[16]In contrast to other more deterministic measures of the frontier, as the Data Envelop Approach (DEA).

and the recent development of econometric methods for estimating auction models, there are many potential gains from combining these two literatures. To the best of my knowledge, this is the first use of auction methods to estimate the costs used in SFA. A related paper is Szucs (2020), who finds that a greater discretion in Hungary leads to reductions in labor productivity and total factor productivity of the selected firms.

When estimating the cost function, I use both the approximated costs from the previous section and additional data on input prices in the street paving production process. Given a level of output and exogenous input prices, the problem of the firm is to choose the input quantity that will minimize the cost of production. Nevertheless, I allow the firms to be technically inefficient when choosing the level of inputs. That is, conditional on a certain level of output, they may use more inputs than necessary. Let $(w, x) \in \mathbb{R}^K \times \mathbb{R}^K$ denote the vector of input prices and quantities respectively, where K represents the total number of inputs, and let $z \in \mathbb{R}^+$ denote the scalar output. Then, following Kumbhakar et al. (2015), the problem of the firm under technical inefficiency is:

$$\begin{aligned} &\min_{x \in X} \; w'x \quad \text{s.t.} \quad z = h(xe^{-\eta}), \\ &F.O.C \quad \frac{h_k(xe^{-\eta})}{h_1(xe^{-\eta})} = \frac{w_k}{w_1}, \text{ for } k = 2, ..., K, \end{aligned}$$

where $\eta \geq 0$ stands for the input-oriented technical inefficiency and $h(\cdot)$ for the production function. Here η represents the percentage by which all the inputs are overused to produce the output level z. Note that z was used as the first element of the vector of controls $\mathbf{z}$ in the auction model. It represents the total amount of concrete in cubic meters that the firm needs to produce, which is the sum of the amount of concrete needed to pave the street, and to construct the sidewalk, a small ramp, and a concrete block beside the sidewalk. For the inputs, I use the prices of one cubic meter of concrete, the average daily wage in the construction industry, and the per-day rent of machinery.

Using the $K-1$ equations from the first order conditions, we can solve for the demand of inputs in their effective units $x_k e^{-\eta}$, and define the frontier cost function as:

$$C^*(w, z) = \sum_{k=1}^{K} w_k x_k e^{-\eta},$$

which represents the minimum costs given the input prices w, and output z, when we allow the firms to be inefficient[17]. Now, when considering the actual costs incurred by the firm C^a, it can be

[17] $C^*(w, z)$, as noted by Kumbhakar et al. (2015), can be considered as the minimum cost function, for the problem: $\min_{x_k e^{-\eta}} w'xe^{-\eta}$ s.t. $z = h(xe^{-\eta})$.

shown that the relationship between the actual and optimal costs can be represented as:

$$\ln C^a = \ln C^*(w, y) + \eta.$$

Notice then, that we can approximate the efficiency of a firm by the estimation of $e^{-\eta}$. For details on the relationship between $C^*(w, z)$ and $\ln C^a$, see the Appendix, sub-section 6.2.1

Estimation of the Cost Function

For the specification of the cost function, as is standard in the literature, I assume a translog representation of $\ln C^*(w, z)$, and consider a noise term ν and some controls.[18] If we use the estimated cost from the auction model as the actual cost, we have:

$$\begin{aligned}
\ln \hat{c}_i =& \ln C_i^*(w, z) + \eta_i + \upsilon_i, \\
\ln \hat{c}_i =& \beta_0 + \sum_k \beta_k \ln w_{k,i} + \beta_z \ln z_i + \frac{1}{2} \sum_k \sum_{k'} \beta_{kk'} \ln w_{k,i} \ln w_{k',i} + \\
& \frac{1}{2} \beta_{zz} \ln z_i \ln z_i + \sum_k \beta_{kz} \ln w_{k,i} \ln z_i + \beta_{K+1} Controls_i + \eta_i + \nu_i.
\end{aligned}$$

The symmetry restrictions on the cost function require that $\beta_{kk'} = \beta_{k'k}$, and homogeneity of degree one in input prices requires:

$$\sum_k \beta_k = 1, \quad \sum_k \beta_{kk'} = 0 \;\; \forall k', \quad \sum_k \beta_{kz} = 0.$$

A natural way of embedding these restrictions in the estimation procedure, is to normalize the actual cost and the input prices by the price of a chosen input. In the current exercise I use three input prices: the daily wage of a construction worker, the price of concrete, and the daily rent of machinery, which will be represented respectively by w_1, w_2 and w_3. To embed the prince homogeneity of the translog especification, I normalize the input prices by the price of labor, w_1. By re-writing the cost function, we have:

$$\begin{aligned}
\ln\left(\frac{\hat{c}_i}{w_{1,i}}\right) =& \beta_0 + \beta_z \ln z_i + \beta_2 \ln\left(\frac{w_{2,i}}{w_{1,i}}\right) + \beta_3 \ln\left(\frac{w_{3,i}}{w_{1,i}}\right) + \frac{1}{2}\beta_{23} \ln\left(\frac{w_{2,i}}{w_{1,i}}\right) \ln\left(\frac{w_{3,i}}{w_{1,i}}\right) + \\
& \frac{1}{2}\beta_{zz}\Big[\ln z_i\Big]^2 + \frac{1}{2}\beta_{22}\left[\ln\left(\frac{w_{2,i}}{w_{1,i}}\right)\right]^2 + \frac{1}{2}\beta_{33}\left[\ln\left(\frac{w_{3,i}}{w_{1,i}}\right)\right]^2 + \\
& \beta_{2z} \ln\left(\frac{w_{2,i}}{w_{1,i}}\right) \ln z_i + \beta_{3z} \ln\left(\frac{w_{2,i}}{w_{1,i}}\right) \ln z_i + \beta_{K+1} Controls_i + \eta_i + \nu_i.
\end{aligned} \tag{11}$$

[18] The error term ν can be interpreted as coming from the error in the cost's estimation.

The estimation of the model is by maximum likelihood, where identification is achieved by the parametric assumption on the error terms. A key advantage of making parametric assumptions on the error term, is that determinants of the mean of the firms' excess costs term, such as the firm's type, can be included. I assume that the statistical error ν_i is normally distributed, with mean zero and standard deviation σ_ν. For the inefficiency term, as in Wang (2002), I assume that it follows a truncated normal, where the mean depends on observable characteristics W (here, the firm's type, whether the project started during the year before municipal elections, and whether the party of the municipality's major coincides with the party of the state's governor), and the standard deviation is σ_η. Given the parametric assumptions on the error terms, where $\eta \sim \ N^+(\mu(W), \sigma_\eta^2)$, and $\upsilon \sim \ N(0, \sigma_\upsilon^2)$, the likelihood function is:

$$L_i = -\frac{1}{2}\ln(\sigma_\eta^2 + \sigma_\upsilon^2) + \ln\phi\left(\frac{\mu(W) - \epsilon}{\sqrt{\sigma_\eta^2 + \sigma_\upsilon^2}}\right) + \ln\Phi\Big(\frac{\mu_{*i}}{\sigma_*}\Big) + \ln\Phi\Big(\frac{\mu(W)}{\sigma_\eta}\Big), \tag{12}$$

where, $\epsilon = \eta + \upsilon$,

$$\mu_{*i} = \frac{\sigma_\nu^2\mu(W) + \sigma_\eta^2\epsilon}{\sigma_\nu^2 + \sigma_\eta^2} \quad \text{and} \quad \sigma_* = \frac{\sigma_\nu^2\sigma_\eta^2}{\sigma_\nu^2 + \sigma_\eta^2}.$$

Using the MLE estimates, we can further estimate the firm's excess use of inputs by $E[\eta_i|\epsilon_i]$, or similarly, we can estimate a firm's efficiency index by $E[\exp(-\eta_i)|\epsilon_i]$. A full description of the estimates of these indices can be found in the Appendix, in sub-section 6.2.

4 Results

Using the public auction data, I first describe the results of the structural auction model, followed by the results of the stochastic frontier analysis.

4.1 Cost and estimates

As a first step, to test whether bidders behave according to the model, I plot the estimated equilibrium strategies for both types of firms, conditional on the median value of the size of the project (measured by the total amount of concrete, z) and on whether the project includes sewage work. As in Flambard and Perrigne (2006), the model rationalizes the data if the firms' bids increase as the private costs increase. The plots of $\hat{\xi}_1^{-1}(\cdot|z, sewage)$ and $\hat{\xi}_0^{-1}(\cdot|z, sewage)$ are displayed in Figure 4 in the Appendix. The estimated equilibrium strategies are increasing on the estimated costs, which provides evidence that the model is supported by the data. Hence, the cost estimates are presented Table 4, with the results for projects with and without sewage work offered separately.

In projects with sewage work, type 1 firms, which have been approached by the government to receive a project by direct allocation or to participate in an auction by invitation, have a lower costs per cubic meter than firms that only participate in public auctions. Nevertheless, this relationship is reversed when looking at projects without sewage work. This is reflected for both the average and median cost of all bidders. The results for the winning firms is more convoluted. For projects with sewage work, type 1 firms have lower costs on average but have a higher median. As for projects without sewage work, the costs of both firms are similar, although lower for type 1 firms.

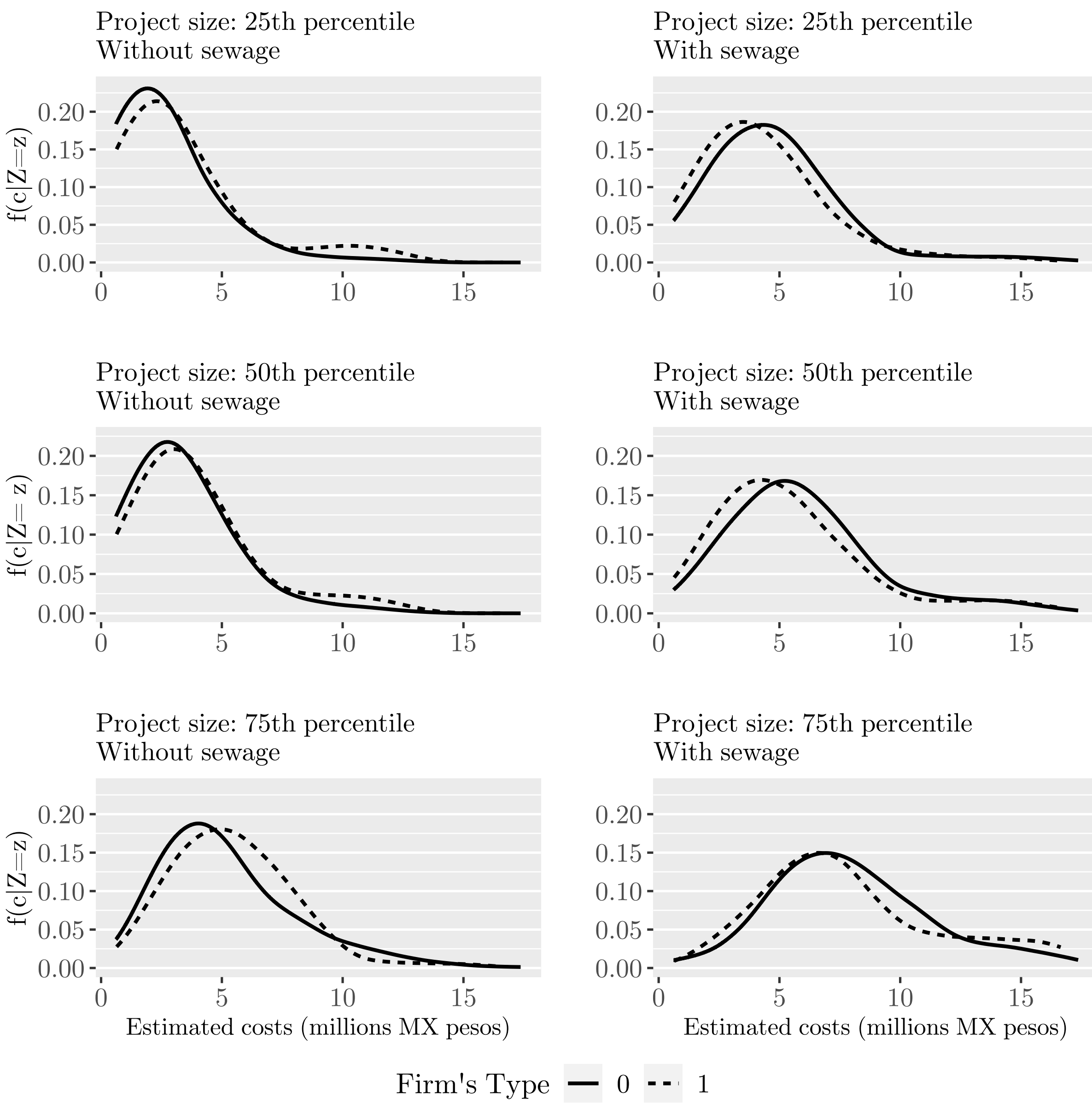
Table 4: Cost estimates

	Mean	Median	S.E.	Obs
Estimated firms' costs (thousands per m^3)				
Projects with sewage work				
Public auction: type 1, $\hat{c}_1$	10.813	8.304	(8.931)	256
Public auction: type 0, $\hat{c}_0$	11.538	9.005	(10.344)	631
Projects without sewage work				
Public auction: type 1, $\hat{c}_1$	7.038	5.800	(5.606)	475
Public auction: type 0, $\hat{c}_0$	6.116	4.958	(4.209)	1115
Estimated winning firms' costs (thousands per m^3)				
Projects with sewage work				
Public auction: type 1, $\hat{c}_1$	10.337	8.398	(6.951)	61
Public auction: type 0, $\hat{c}_0$	10.827	7.347	(11.017)	59
Projects without sewage work				
Public auction: type 1, $\hat{c}_1$	6.271	4.843	(5.418)	78
Public auction: type 0, $\hat{c}_0$	6.495	4.991	(4.552)	126

Note: public auction data, where 18 outliers have been dropped. $\hat{c}_1$ denotes the estimated costs of type 1 firms (firms that, in addition to participating in public auctions, have participated in an auction by invitation or received a project by direct allocation), and $\hat{c}_0$ denotes the estimated costs of type 0 firms (firms that only participate in public auctions). b_1 and b_0 denotes the bids of firm types 1 and 0, respectively.

To further understand the cost differences between type 1 and type 0 firms, I plot in Figure 1 the estimated cost distributions, conditional on different levels of the total amount of concrete z, and whether the project includes sewage work. Conditioning the cost distributions on the amount of concrete allows me to control for the size of the project, and conditioning the cost distribution for whether the project includes sewage work allows me to control for the contracts' complexity. The different project sizes I condition for correspond to the 25th, 50th and 75th percentiles of the total amount of concrete used in a project.

Figure 1: Conditional cost density, evaluated at different project characteristics ($\mathbf{z}$)



Type 1: firms that, in addition to participating in public auctions, have participated in an auction by invitation or received a project by direct allocation. Type 0: firms that only participate in public auctions.

For all project sizes, firms selected to settings with less competition, type 1 firms, have lower costs for projects with sewage work, but higher costs for projects without sewage work[19]. That is, type 1 firms have lower costs in complex projects, but less so in simple ones. A possible explanation is that type 1 firms may use economies of scope to be more competitive in complex projects, where they leverage the cost complementarites of the different services they provide (sewage and pavement work). Alternatively, smaller and less experienced firms, consistent with product differentiation, may specialize in simpler projects where larger firms do not have a cost advantage when providing a single service.

4.2 Over use of inputs estimates

The cost function described in equation (12) is estimated by maximum likelihood using the cost estimates from the structural model, $\hat{c}_1$ and $\hat{c}_0$, along with augmented data on input prices. The three inputs used are concrete, labor, and capital. The price of labor is approximated using the daily wage of construction workers at the municipality level based census data from the National Institute of Statistics and Geography (INEGI). The census in Mexico is performed every 10 years and, in between, a survey is conducted at a lower scale. The census of 2010 and the 2015 count are used here to approximate the wages at the municipality level, interpolating the data to approximate the wages for the years in between and after 2015. For the concrete and rent of capital, I estimate the costs at the state level using market prices given by construction material suppliers in each state. Next, I use an INEGI's monthly price index at the state level for the construction sector and rent of machinery to approximate the prices between 2011 and 2018.

First, the theoretical requirements of the estimation of a translog cost function are checked. As mentioned above, the homogeneity of degree one was embedded in the estimation by normalizing the cost and input prices by the price of one of the inputs. Here, prices are normalized by the price of labor. Two other conditions that need to be met are monotonicity and concavity in input prices and output. To review the monotonicity condition, as in Kumbhakar et al. (2015), I check the sign of the partial derivative of the log of costs with respect to the log of input prices. These derivatives are functions of $\ln z_i$ and $\ln w_{j_i}$ for $j = 1, ..., K$, and as such are observation-specific. There are no violations of monotonicity for the output and price of labor, although a violation can be found in 45

[19] Kolmogorov-Smirnov tests of the equality of distributions are rejected for the conditional cost densities evaluated at different project sizes: z's 25th, 50th and 75th percentile

and 23 percent of the observations for the prices of concrete and capital. Nevertheless, for the case of capital prices, these violations happen at the tails of the data. To test concavity, I calculate the Hessian matrix with respect to input prices, which is also data-dependent and therefore verifiable. Only 13 percent of the observations present a concavity violation, but, again, this happens at the tails of the data. With evidence that the model conforms to the data, I proceed to describe the results in Table 5.

Table 5: SFA - Cost function estimates

	Coef.	S.E.		Coef.	S.E.
Frontier			μ		
β_z	0.150	(0.246)	Dummy(Firm's type)	1.501	(1.210)
β_{zz}	0.093**	(0.039)	Dummy(1yr. before elec.)	2.751	(2.090)
β_{w_2}	2.269***	(0.358)	Dummy(Mayor and Gov.	−1.824	(1.436)
β_{w_3}	−1.291***	(0.380)	from the same party)		
$\beta_{w_{2,2}}$	−2.386***	(0.187)	Constant	−7.272	(6.721)
$\beta_{w_{3,3}}$	−2.272***	(0.202)	σ_η		
$\beta_{w_{2,3}}$	2.356***	(0.191)	Constant	1.116	(0.817)
$\beta_{2,z}$	−0.331***	(0.055)	σ_ν		
$\beta_{3,z}$	0.329***	(0.058)	Constant	−2.093***	(0.064)
Wald Chi2			26591.41		
Returns to scale			1.303		
Observations			2482		
Controls			Yes		

Note: *** p<0.01, ** p<0.05, * p<0.1. The βs denote the fit of the cost frontier, where β_z is the coefficient for the normalized log of output, and β_{w_2} and β_{w_3} the coefficients for the normalized log of the second and third input prices (price of concrete and rent of machinery respectively). The normalization was made using the price of labor. μ and σ_η denote the mean and variance of the inefficiency term, and σ_ν the variance of the idiosyncratic error.

The fit of the frontier is good (measured by the fit of the βs), and the returns to scale appropriate for the context of small construction projects, where we would expect gains to returns to scale. To aid in the numerical optimization of the likelihood, I assume that the variance of the error terms follow an exponential distribution. Hence, the constant for σ_ν represents $\exp(1.116) = 3.052$, and the constant for σ_η represents $\exp(-2.093) = 0.123$. As for the mean of the excess use of inputs term, μ, an important advantage of making parametric assumptions on the error term is that we can include observable determinants of it. I estimate the mean of the excess use of inputs term as a function of the firm's type, whether the project started one year before a municipal election, and whether the political parties of the municipality's mayor and state's governor were aligned. The coefficients are informative but cannot be interpreted directly, given the non-linearity of the model. For a clearer interpretation, I report in Table 6 the marginal effects of these variables on the unconditional mean of the inefficiency term, as well as on its unconditional variance. For a description of the estimation of the marginal effects, see the Appendix, sub-section 6.2.2.

Table 6: SFA - Marginal Effects on the mean and variance of the overuse of inputs term ($E[\eta]$ and $V[\eta]$)

	Coef.	S.E.
Firm's type		
Marginal Effect on $E[\eta]$	0.075^{***}	(0.020)
Marginal Effect on $V[\eta]$	0.053^{***}	(0.014)
Dummy, 1 year before elections		
Marginal Effect on $E[\eta]$	0.138^{***}	(0.019)
Marginal Effect on $V[\eta]$	0.098^{***}	(0.017)
Dummy, Mun. Mayor and Governor from the same party		
Marginal Effect on $E[\eta]$	-0.098^{***}	(0.024)
Marginal Effect on $V[\eta]$	-0.065^{***}	(0.016)
Observations	2482	

Bootstrapped standard errors in parentheses, using 500 iterations.
*** p<0.01, ** p<0.05, * p<0.1 .

Table 6 shows that type 1 firms overuse inputs by 7.5 percent more than type 0 firms. This difference is significant, and is driven by the fact that the majority of projects do not include sewage work, the type of projects in which type 1 firms are less competitive. When looking at political factors influencing the firm's productivity, the timing of the project matters. If the project started during the year before municipal elections, the average level of overuse of inputs increased by 13.8 percent. All else equal, the overuse of inputs would translate into a 13.8 percent increase in costs. Finally, we observe that when the party of the municipality's mayor is aligned with the party of the state's governor, the average level of overuse of inputs decreased by 9.8 percent. Although I cannot empirically test the reasons behind this difference, a possible explanation is a better coordination between the municipality and state administration when the parties are aligned, which in turn may decrease delays due to bureaucracy, or side payments to speed up the process.

These differences take place in a setting with relatively low efficiency. When calculating the efficiency index $E[\exp(-\eta)]$, on average, type 0 firms have a higher efficiency index, with a weighted average of 0.68 (i.e., on average, the minimum cost is 68 percent of the actual cost), compared to the weighted average of type 1 firms of 0.62. The comparison of the efficiency index between the two groups follows Färe, Grosskopf, and Zelenyuk (2004), and Sickles and Zelenyuk (2019), weighting each firm's efficiency index by the cost share of its respective group. For a further description of the differences in the efficiency index, I plot in Figure 5 in the Appendix the density of the unweighted efficiency index by firm type. As a robustness analysis, I fit a corrected OLS and a Half-Normal model. A plot comparing the distribution of the different efficiency indexes can be found in the Appendix in Figure 6. The full results are available upon request. The corrected OLS model under-predicts efficiency, whereas the Half-Normal presents very similar results to the truncated normal. Likelihood-Ratio (LR) tests are performed to choose the model, finding that the truncated-normal dominates the other two. Finally, in sub-section 6.2.5, the results of the Truncated-Normal are compared with estimates from model specifications that follow the scaling property of Wang and Schmidt (2002). The marginal effects of the exogenous determinants of overuse of inputs, the main estimates I am after, change very little. Nevertheless, in order to achieve convergence under specifications with the scaling property, the number of parameters to be estimated needs to be restricted. Hence, the Truncated-Normal estimates are presented, and the above comparison is detailed in the Appendix, sub-section 6.2.5.

Regional profiles: average efficiency of firms

The results above are useful to study the profile of different regions. We can both aggregate the firm level estimates to study regional differences and also identify the regions where the government's selection of firms to settings with less competition is poor. That is, within a region where the local government allocates projects by direct allocation or auction by invitation, we can identify whether the government is selecting the firms with the lowest excess costs or the firms with the highest excess costs. Given that we are studying rather small homogenous auctionable objects, the cost concerns take priority[20]. The former result can help policy makers in the regional targeting of policies that seek to enhance productivity, whereas the latter results can improve monitoring tools for the proper administration of public funds. In the next paragraphs I briefly describe state

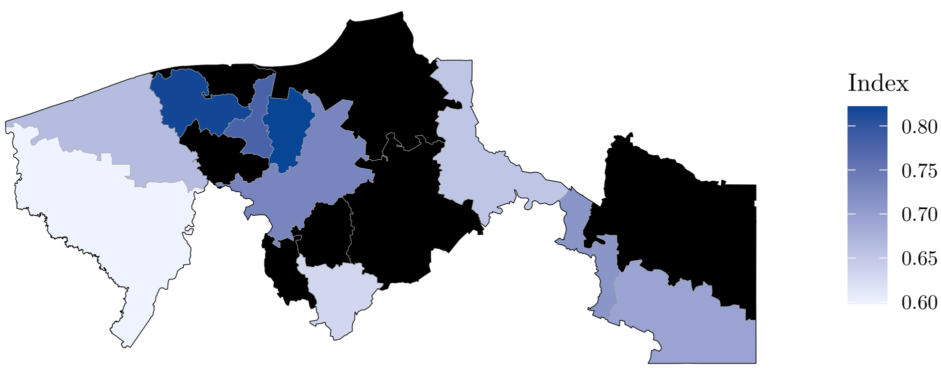
[20] For larger projects, such as highways, quality concerns would become more relevant than in the projects studied here. Furthermore, although controling for quality would be preferable, such data is not available.

differences when agregating the firms' efficiency index, followed by an analysis at the municipal level of the state of Tabasco.

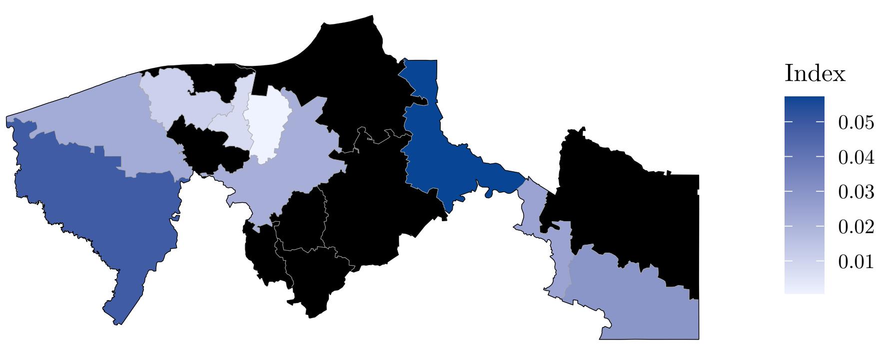
When comparing states, each firm's index is weighted by the cost share of its respective region. See the Appendix, Figure 7, for a map at the state level. The northern states (with the exception of Coahuila, the state in light blue among the states in the northern border), along with states in the gulf, have the firms with the lowest excess costs. The states in the central region, along with the state in the far south, Chiapas, fare the worst. Nevertheless, within each state, there is high heterogeneity between municipalities. For example, Figure 2 focuses on the state of Tabasco.

Figure 2: Efficiency Profile of the State of Tabasco

A. Efficiency index



B. Efficiency difference at the municipality level: average efficiency of type 1 firms vs firm with the lowest excess costs



Note: In black if there are no projects within the municipality in the sample studied. The efficiency index is estimated by $E[\exp(-\eta_i)|\epsilon_i]$ and ranges from 0 to 1. For interpretation purposes, a value of 0.6 denotes that the minimum cost is 60 percent of the actual cost.

In panel A of Figure 2, I plot the weighted average efficiency index of the firms within a municipality. We see a similar range as the one observed when comparing states. In panel B, I plot the difference between the municipality's firm with the lowest excess costs, and the average efficiency of type 1 firms in the municipality (firms that are selected by the government to participate in settings with less competition). The higher the difference, the worse the local government selection of firms to participate in settings with less competition.

In Figure 2, the municipality to the far left and south is the municipality of Huimanguillo. Just above it, and second from the left, lies the municipality of Cárdenas. From Panel A we observe that the average productivity of firms from both municipalities are lower compared to the average productivity of firms in other municipalities in the state. But from Panel B, we observe that Himanguillo's local government is selecting firms with low excess costs within the municipality, whereas the municipality of Cárdenas is doing the opposite. The additional information in Panel B points to the need for further monitoring in Cárdenas to inquire about the selection procedure of the firms that receive projects by direct allocation or are invited to an auction. These results can enhance the government's monitoring capabilities in both the allocation of funds and in the selection of contract allocation procedures.

5 Conclusions

I study the allocation of street pavement contracts with hydraulic concrete in Mexico. By law, the government should favor the use of public procurement auctions for the pavement of streets, but exceptions in the law allow the government to bypass a public auction, and to either choose a firm of its preference or invite specific firms to an auction. In this paper, I test whether the government chooses the firms with the lowest excess costs when bypassing a public procurement auction.

To compare the firms selected to settings with less competition, with the firms that only participate in public auctions, I use the fact that most firms that win projects by direct allocation or participate in auctions by invitation, also participate in public auctions. Hence, I study their bidding behavior in public auctions to recover their cost distribution. Furthermore, the estimation of the pseudo costs is augmented with the price of inputs for street paving. Such data permits the the use of a stochastic frontier analysis to estimate a cost frontier and the firm's excess use of inputs, which is estimated by the distance between the firm's productivity and the estimated cost frontier. This methodology is especially useful when the auctioned object is homogeneous and small, and in the absence of data on the quality of the work delivered to the government, and/or on the reputation of the firms competing for the public contract. The methodology used can be applied to study the allocation of other types of contracts, provided the modeling of the auction is adjusted considering the characteristics of the auctioned object.

Firms selected to receive projects by direction allocation or to participate in auctions by invitation are found to be more experienced and have lower costs for complex projects (contracts that include sewage work). Nevertheless, for smaller projects, they have higher costs than firms that only participate in public auctions. Overall, the above results suggest that the government would benefit from a greater use of public auctions for simple and small projects, with potential savings of around 4.5 percent per contract. This result is especially important given the current practice of using auctions by invitation for small and simple projects, since 75 percent of pavement contracts under auctions by invitation do not include sewage work. This policy is not optimal because the invited firms are not competitive in these type of projects. Opening up the small contracts to public auctions would have the double benefit of supporting smaller firms and achieving lower contract prices.

When studying the influence of political factors on contract allocations, I find that local governments prefer allocation mechanisms with greater hiring discretion during the year before municipal elections, where I document a six percent increase in the probability that the contractual office will avoid public auctions. As for the influence of political factors on the firms' overuse of inputs, I find that during the year before local elections, the average overuse of inputs increases by 13.8 percent under public auctions (compared to other public auction contracts in non-electoral times). Finally, when the mayor's political party is aligned with the governor's party, the firms' average excess use of inputs decreases by 9.8 percent in public auctions. This increase in productivity may be due to a decrease in bureaucracy or to better coordination between the local and state government. Given the latent corruption concerns in Mexico, the results point to the need for further research, studying the influence of political factors over different allocation mechanisms with varying degrees of hiring discretion on the government's part.

References

Abbott, A., Cabral, R., & Jones, P. (2017). Incumbency and Distributive Politics: Intergovernmental Transfers in Mexico. *Southern Economic Journal*, *84*(2), 484–503. doi: 10.1002/soej.12226

Aitchison, J., & Aitken, C. (1976). Multivariate Binary Discrimination by the Kernel Method. *Biometrika*, *63*(3), 413–420.

Bajari, P. (2001). Comparing competition and collusion: a numerical approach. *Economic Theory*, *18*(1), 187-205.

Bajari, P., Houghton, S., & Tadelis, S. (2014). Bidding for incomplete contracts: An empirical analysis of adaptation costs. *American Economic Review*, *104*(4), 1288–1319. doi: 10.1257/aer.104.4.1288

Bajari, P., McMillan, R., & Tadelis, S. (2009). Auctions versus negotiations in procurement: An empirical analysis. *Journal of Law, Economics, and Organization*, *25*(2), 372–399. doi: 10.1093/jleo/ewn002

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

Baldi, S., Bottasso, A., Conti, M., & Piccardo, C. (2016). To bid or not to bid: That is the question: Public procurement, project complexity and corruption. *European Journal of Political Economy*, *43*(April 2018), 89–106. doi: 10.1016/j.ejpoleco.2016.04.002

Banerjee, A. V., & Duflo, E. (2000). Reputation Effects and the Limits of Contracting: a Study of the Indian Software Industry. *Quarterly Journal of Economics*(August), 989–1018.

Battese, G. E., & Coelli, T. J. (1988). Prediction of firm-level technical efficiencies with a generalized frontier production function and panel data. *Journal of Econometrics*, *38*(3), 387–399. doi: 10.1016/0304-4076(88)90053-X

Behr, A. (2015). *Production and efficiency analysis with r*. Switzerland: Springer.

Bulow, J., & Klemperer, P. (1996). Auctions versus Negotiations. *American Economic Review*, *86*(1), 180–194.

Bulow, J., & Klemperer, P. (2009). Why do sellers (usually) prefer auctions? *American*

Economic Review, *99*(4), 1544–1575. doi: 10.1257/aer.99.4.1544

Calzolari, G., & Spagnolo, G. (2010). Relational Contracts and Competitive Screening. *CEPR Discussion Paper No 7434*, 1–30.

Campo, S., Perrigne, I., & Vuong, Q. (2003). Asymmetry in first-price auctions with affiliated private values. *Journal of Applied Econometrics*, *18*(2), 179–207. doi: 10.1002/jae.697

Carril, R. (2021). Rules versus Discretion in Public Procurement. *Working paper - Universitat Pompeu Fabra*(1), 1–79. Retrieved from https://econ-papers.upf.edu/papers/1765.pdf

Coviello, D., Guglielmo, A., & Spagnolo, G. (2018). The effect of discretion on procurement performance. *Management Science*, *64*(2), 715–738. doi: 10.1287/mnsc.2016.2628

Decarolis, F., Fisman, R., Pinotti, P., & Vannutelli, S. (2021). Rules, Discretion, and Corruption in Procurement: Evidence from Italian Government Contracting. *NBER, Working Paper 28209*.

Elyakime, B., Laffont, J. J., Loisel, P., & Vuong, Q. (1994). First-Price Sealed-Bid Auctions with Secret Reservation Prices. *Annales d'Économie et de Statistique*, *Apr.-Jun.*(34), 115. doi: 10.2307/20075949

Elyakime, B., Laffont, J. J., Loisel, P., & Vuong, Q. (1997). Auctioning and bargaining: An econometric study of timber auctions with secret reservation prices. *Journal of Business and Economic Statistics*, *15*(2), 209–220. doi: 10.1080/07350015.1997.10524701

Färe, R., Grosskopf, S., & Zelenyuk, V. (2004). Aggregation of Cost Efficiency : Indicators and Indexes Across Firms Department of Agricultural and Resource Economics Department of Economics Economics Education and Research Consortium. *Academia Economic Papers*, *32*(3), 395–411.

Flambard, V., & Perrigne, I. (2006). Asymmetry in Procurement Auctions : Evidence From Snow Removal Contracts. *The Economic Journal*, *116*(October), 1014–1036.

Greene, W. H. (2008). The Econometric Approach to Efficiency Analysis. In H. O. Fried, K. Lovell, & P. Schmidt (Eds.), *The measurement of productive efficiency and productivity change* (pp. 92–250). Oxford University Press. doi: 10.1080/00958979408024270

Guerre, E., Perrigne, I., & Vuong, Q. (2000). Optimal Nonparametric Estimation of First-Price Auctions Author (s): Published by : The Econometric Society Stable URL : .

Econometrica, *68*(3), 525–574. doi: 10.1111/1468-0262.00123

Haile, P. A., Hong, H., & Shum, M. (2003). Nonparametric Tests for Common Values. *Working Paper*.

Hendricks, K., Pinkse, J., & Porter, R. H. (2003). Empirical implications of equilibrium bidding in first-price, symmetric, common value auctions. *Review of Economic Studies*, *70*(1), 115–145. doi: 10.1111/1467-937X.00239

Herweg, F., & Schmidt, K. M. (2017). Auctions versus negotiations: the effects of inefficient renegotiation. *RAND Journal of Economics*, *48*(3), 647–672. doi: 10.1111/1756-2171.12189

Hickman, B. R., & Hubbard, T. P. (2015). Replacing Sample Trimming with Boundary Correction in Nonparametric Estimation of First-Price Auctions. *Jornal of Applied Econometrics*, *30*(5), 739–762.

Hickman, B. R., Hubbard, T. P., & Sağlam, Y. (2012). Structural Econometric Methods in Auctions: A Guide to the Literature. *Journal of Econometric Methods*, *1*(1), 1–67. doi: 10.1515/2156-6674.1019

Hong, H., & Shum, M. (2002). Increasing competition and the winner's curse: Evidence from procurement. *Review of Economic Studies*, *69*(4), 871–898. doi: 10.1111/1467-937X.00229

Hu, Y., McAdams, D., & Shum, M. (2013). Identification of first-price auctions with non-separable unobserved heterogeneity. *Journal of Econometrics*, *174*(2), 186–193. doi: 10.1016/j.jeconom.2013.02.005

Jofre-Bonet, M., & Pesendorfer, M. (2003). Estimation of a Dynamic Auction Game. *Econometrica*, *5*, 1443–1489.

Krasnokutskaya, E. (2011). Identification and estimation of auction models with unobserved heterogeneity. *Review of Economic Studies*, *78*(1), 293–327. doi: 10.1093/restud/rdq004

Krasnokutskaya, E., & Seim, K. (2011). Bid preference programs and participation in highway procurement auctions. *American Economic Review*, *101*(6), 2653–2686. doi: 10.1257/aer.101.6.2653

Kumbhakar, S. C., Wang, H.-j., & Horncastle, A. (2015). *A practitioner's guide to stochastic* *frontier analysis using stata*. New York: Cambridge University Press.

Lamy, L. (2012). The econometrics of auctions with asymmetric anonymous bidders. *Journal of Econometrics*, *167*(1), 113–132. doi: 10.1016/j.jeconom.2011.10.007

Li, T., & Perrigne, I. (2003). Timber sale auctions with random reserve prices. *Review of Economics and Statistics*, *85*(1), 189–200. doi: 10.1162/003465303762687802

Luo, Y., Perrigne, I., & Vuong, Q. (2016). Cost Uncertainty in Procurements. *Working Paper - Rice University*.

Marion, J. (2007). Are bid preferences benign? The effect of small business subsidies in highway procurement auctions. *Journal of Public Economics*, *91*(7-8), 1591–1624. doi: 10.1016/j.jpubeco.2006.12.005

Maskin, E., & Riley, J. (2000). Asymmetric Auctions. *Review of Economic Studies*, *67*, 413–438.

Maskin, Eric and Riley, John. (2000). Equilibrium in Sealed High Bid Auctions. *Review of Economic Studies*, *67*(3), 439–454.

Perrigne, I., & Vuong, Q. (2019). Econometrics of Auctions and Nonlinear Pricing. *Annual Review of Economics*, *11*(1), 27–54. doi: 10.1146/annurev-economics-080218-025702

Roberts, J. W., & Sweeting, A. (2013). When should sellers use auctions? *American Economic Review*, *103*(5), 1830–1861. doi: 10.1257/aer.103.5.1830

Sickles, R. C., & Zelenyuk, V. (2019). *Measurement of Productivity and Efficiency* (No. May). New York: Cambridge University Press.

Spagnolo, G. (2012). Reputation, competition, and entry in procurement. *International Journal of Industrial Organization*, *30*(3), 291–296. doi: 10.1016/j.ijindorg.2012.01.001

Szucs, F. (2020). Discretion and Favoritism in Public Procurement. *Working Paper - Stockholm University*.

Wang, H. J. (2002). Heteroscedasticity and non-monotonic efficiency effects of a stochastic frontier model. *Journal of Productivity Analysis*, *18*(3), 241–253. doi: 10.1023/A:1020638827640

Wang, H. J., & Schmidt, P. (2002). One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels. *Journal of Productivity Analysis*, *18*(2), 129–144. doi: 10.1023/A:1016565719882

Zhang, B., & Guler, K. (2005). Nonparametric estimation of asymmetric first price auctions: A simplified approach. *Economics Letters*, *88*(3), 318–322. doi: 10.1016/j.econlet.2004.12.033

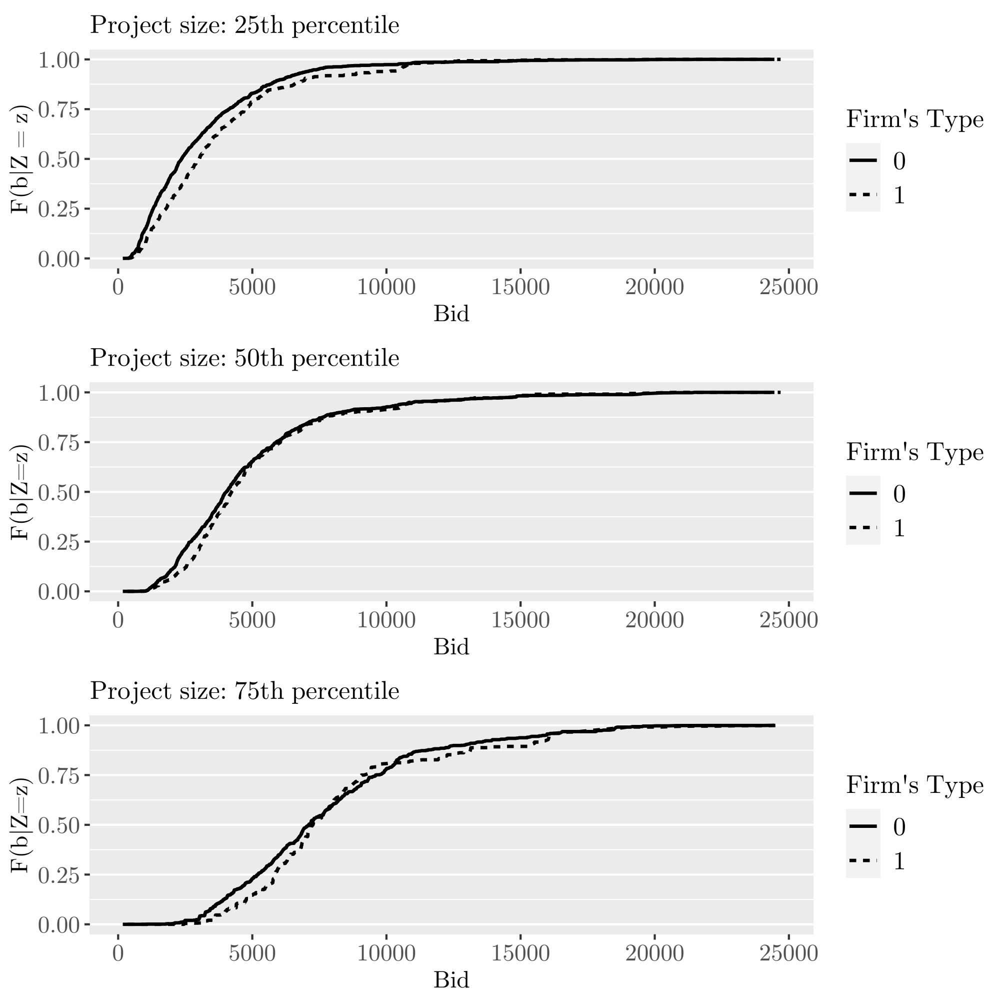
6 Appendix

6.1 Estimation details of the procurement auction model

6.1.1 Evidence of asymmetry

Figure 3 shows the conditional bid cdfs evaluated at different project sizes, approximated by the total amount of concrete z. When evaluating the cdfs at z's 50th percentile, the distributions are quite similar. Nevertheless, this changes when evaluating the cdfs for small and larger projects. Especially for smaller projects, type 0 firms dominate type 1 firms.

Figure 3: Conditional bid CDFs evaluated at different project sizes, z

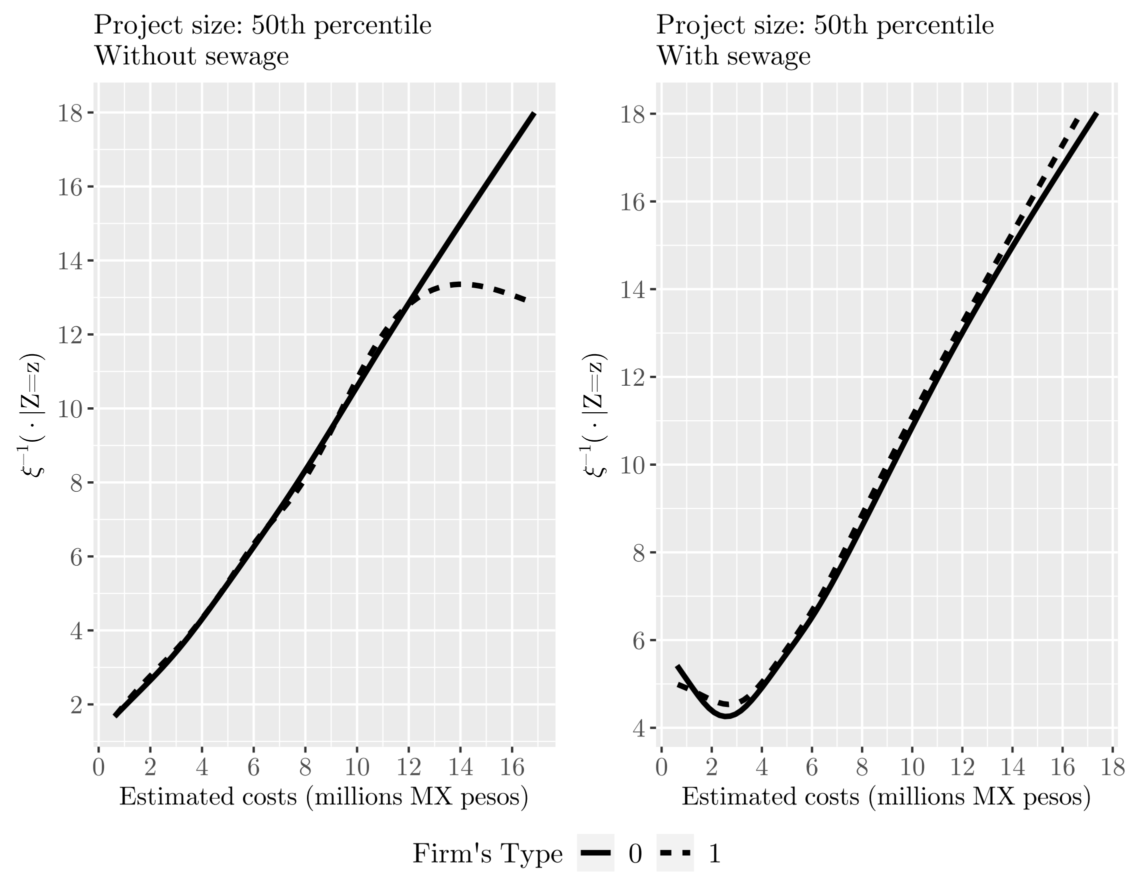


Type 1: firms that, in addition to participating in public auctions, have participated in an auction by invitation or received a project by direct allocation. Type 0: firms that only participate in public auctions.

6.1.2 Evidence to support the model - public auction

A key assumption of the structural procurement auction model is that the firm's strategy functions are strictly increasing in its cost. Figure 4 shows the estimated strategy functions and the estimated costs. As expected, the functions are increasing for both types of firms, with a few exceptions on the tails.

Figure 4: $\xi^{-1}(\cdot|z)$ evaluated at the median of the project size



Type 1: firms that, in addition to participating in public auctions, have participated in an auction by invitation or received a project by direct allocation. Type 0: firms that only participate in public auctions.

6.1.3 Bid data of auctions by invitation (I3P)

Find in Table 7 the bid data of auctions by invitation and, for easy of comparison, the bid data of public auctions from Table 1. Overall, the median bid per cubic meter is lower under I3P. The projects under I3P are half the size of projects allocated by public auctions, but take on average only 10 percent less time to complete. A lower proportion of I3P projects include sewage work, 24 percent against 38 percent of public auctions, and an equal proportion of projects are allocated by the municipality (compared to the state government) in both auction formats.

Table 7: Summary statistics, first-price sealed bid auctions - auctions by invitation and public auctions

	Mean	Median	S.D.	Min	Max	Obs
Auctions by invitation (I3P)						
Bids/m^3 concrete	7.96	6.66	6.17	0.52	86.9	3895
Winner: bid/m^3 concrete	7.70	6.46	5.85	0.81	65.1	1266
Number of bidders	3.08	3	0.66	1	11	1266
M^3 concrete	355.8	271.6	358.8	6.21	6185.8	1266
Dummy, project includes sewage work	0.24	0	0.43	0	1	1266
Duration of project (months)	3.13	2	5.45	0	49	1266
Dummy, municipality project	0.83	1	0.38	0	1	1266
Public Auctions						
Bids/m^3 concrete (thousands per m3)	9.01	7.13	7.57	0.87	92.6	2784
Winning bid/m^3 concrete	9.40	7.45	7.49	1.31	62.1	404
Number of bidders: total	6.89	5	6.22	1	35	404
Num. bidders: at some point Direct/I3P	2.03	2	2.15	0	15	404
Num. bidders: only Public Auction	4.86	3	5.24	0	35	404
M^3 concrete	730.8	588.4	574.9	23.5	4072.9	404
Dummy, project includes sewage work	0.38	0	0.49	0	1	404
Duration of project (months)	3.44	3	3.91	0	49	404
Dummy, municipality project	0.84	1	0.36	0	1	404

6.2 Estimation details of the stochastic frontier analysis

6.2.1 Relationship between the cost frontier and the actual cost.

Using Shephard's lemma, we notice:

$$\frac{\partial C^*}{\partial w_k} = x_k e^{-\eta},$$

$$\Rightarrow \frac{\partial \ln C^*}{\partial \ln w_k} = \frac{w_k x_k e^{-\eta}}{C^*} = \frac{w_k x_k}{w' x} = S_k,$$

where S_k denotes the input k's share of the total cost. By rearrenging terms, we then have that $x_k = \frac{C^* S_k}{e^{-\eta} w_k}$, therefore, when calculating the actual cost:

$$C^a = \sum_k w_k x_k = \sum_k \frac{w_k C^* S_k}{e^{-\eta} w_k} = \frac{C^*}{e^{-\eta}} \sum_k S_k = C^* exp(\eta),$$
$$\Rightarrow \ln C^a = \ln C^* + \eta.$$

6.2.2 Estimation of the efficiency index and marginal effects on $E[\eta]$.

Note that the conditional distribution of η is known, so we can derive moments of the continuous function of $\eta|\epsilon$, where $\epsilon = \eta + \nu$. Following Battese and Coelli (1988), we can show:

$$E[\eta_i|\epsilon_i] = \frac{\sigma_* \phi(\frac{\mu_{*i}}{\sigma_*})}{\Phi\Big(\frac{\mu_{*i}}{\sigma_*}\Big)} + \mu_{*i},$$
$$E[exp(-\eta_i)|\epsilon_i] = exp\Big(- \mu_{*i} + \frac{1}{2}\sigma_*^2\Big) \frac{\Phi\Big(\frac{\mu_{*i}}{\sigma_*} - \sigma_*\Big)}{\Phi\Big(\frac{\mu_{*i}}{\sigma_*}\Big)}.$$

For the marginal effects of η's mean determinants, I follow Wang (2002). If $E[\eta_i] = \mathbf{w}_i'\boldsymbol{\delta}$, we have:

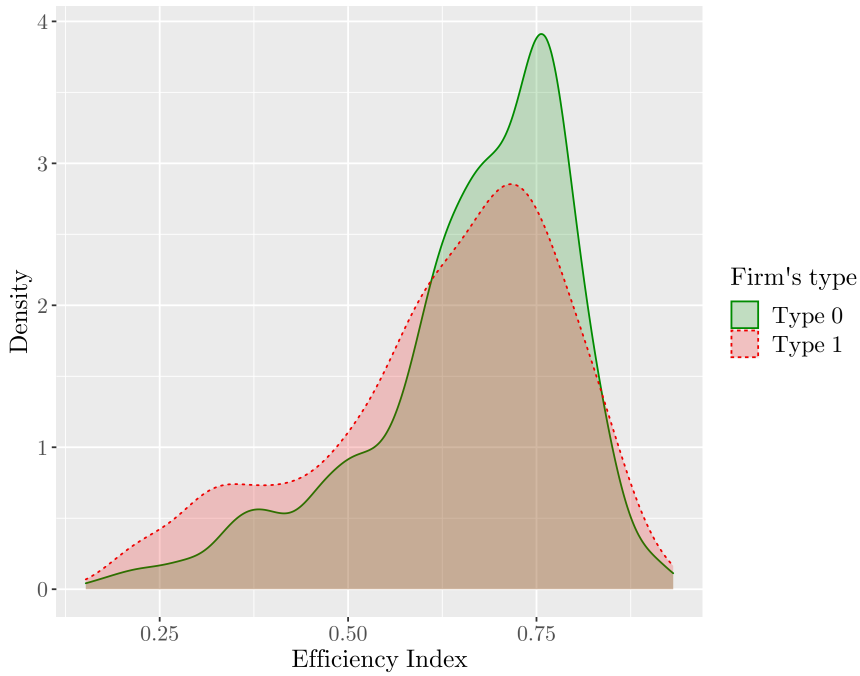
$$\frac{\partial E(\eta_i)}{\partial \mathrm{w}_r} = \delta_r \Bigg[1 - \Lambda_i \Big[\frac{\phi(\Lambda_i)}{\Phi(\Lambda_i)}\Big] - \Big[\frac{\phi(\Lambda_i)}{\Phi(\Lambda_i)}\Big]^2 \Bigg],$$
$$\frac{\partial V(\eta_i)}{\partial \mathrm{w}_r} = \frac{\delta_r}{\sigma_\eta} \Big[\frac{\phi(\Lambda_i)}{\Phi(\Lambda_i)}\Big] (E(\eta_i)^2 - V(\eta)),$$

where $\Lambda_i = \mu_i/\sigma_\eta$.

6.2.3 Distribution of the efficiency index by firm type and allocation procedure.

See in Figure 5 the unweighted distribution of the efficiency index by firm type, using the public auctions. In the estimation, three inputs are used assuming that the inefficiency term η follows a Truncated-Normal, with its mean being influenced by three observable characteristics: the firm's type, whether the project takes place during the year before elections, and a dummy for party alignment between the mayor and governor. We see that type 0 firms have a higher efficiency index. This is mainly driven by the fact that they are more efficient in projects without sewage work, which are more common than projects with sewage work.

Figure 5: Densities - Efficiency index

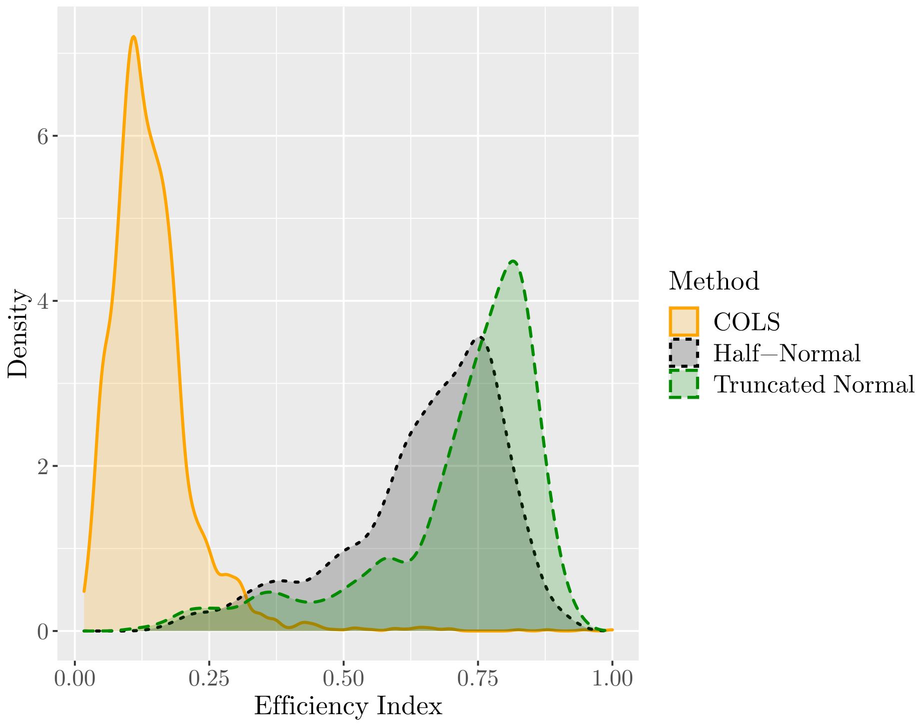


Type 1: firms that, in addition to participating in public auctions, have participated in an auction by invitation or received a project by direct allocation. Type 0: firms that only participate in public auctions. The efficiency index is estimated by $E[\exp(-\eta_i)|\epsilon_i]$ and ranges from 0 to 1. For interpretation purposes, a value of 0.6 denotes that the minimum cost is 60 percent of the actual cost.

6.2.4 Robustness analysis: Truncated Normal vs COLS and Half-Normal

When estimating the SFA model, I estimate a corrected OLS (COLS) and a Half-Normal model as a robustness analysis. The full results are available upon request. Figure 6 displays the efficiency indexes of these two estimates, along with the results from the Truncated-Normal model. The COLS are very different, but this method is known to be especially sensitive to outliers. When estimating the model by maximum likelihood assuming a Half-Normal distribution of the inefficiency term, the results are similar to the model estimated using the Truncated-Normal specification. A Likelihood-Ratio test reveals that the Truncated-Normal model is the preferred specification.

Figure 6: Histogram - Efficiency index (COLS, Half-Normal and Truncated-Normal)



The efficiency index is estimated by $E[\exp(-\eta_i)|\epsilon_i]$ and it ranges from 0 to 1. For interpretation purposes, a value of 0.6 denotes that the minimum cost is 60 percent of the actual cost.

6.2.5 Robustness analysis: model specification with scaling property

A comparison of the Truncated-Normal model with model specifications under the scaling property of Wang and Schmidt (2002) deserves further discussion. So far, under the Truncated-Normal specification, I have parameterized the mean of the inefficiency term as a function of external variables $\mathbf{w}$. Alternatively, Wang and Schmidt (2002) propose that the inefficiency term η may follow the form, $\eta_i \sim h(\mathbf{w}_i, \delta)\eta*$. With some abuse of notation, the function $h(\cdot) \geq 0$ does not represent the production function as above, but rather any observation specific non-stochastic function of the exogenous determinants of the inefficiency term, and $\eta* \geq 0$ is a random variable, common to all observations. The authors call $h(\cdot)$ the scaling function, and $\eta*$ the basic distribution. Models with the scaling property are attractive because the shape of the inefficiency term η_i is the same for all firms, and $h(\cdot)$ scales the distribution. In comparison, for the Truncated Normal specification, where the mean of η is parameterized, each observation has a different truncation point.

Table 8: Robustness analysis: comparing the Truncated-Normal with specifications with the scaling property

Specification restrictions		Marginal Effects on $E[\eta]$		
Translog restrictions	Number of inputs	Type of firm	Dummy (1yr before elections)	Dummy (same party: mayor-governor)
Public Auctions				
Truncated Normal				
None	3	0.07	0.13	-0.09
None	2	0.09	0.12	-0.16
Truncated Normal with scaling property				
No quadratic	3	0.07	0.12	-0.17
Half-Normal				
No interactions	3	0.07	0.11	-0.18
No quadratic	3	0.07	0.11	-0.17
No interactions	2	0.05	0.10	-0.14
No quadratic	2	0.07	0.11	-0.18

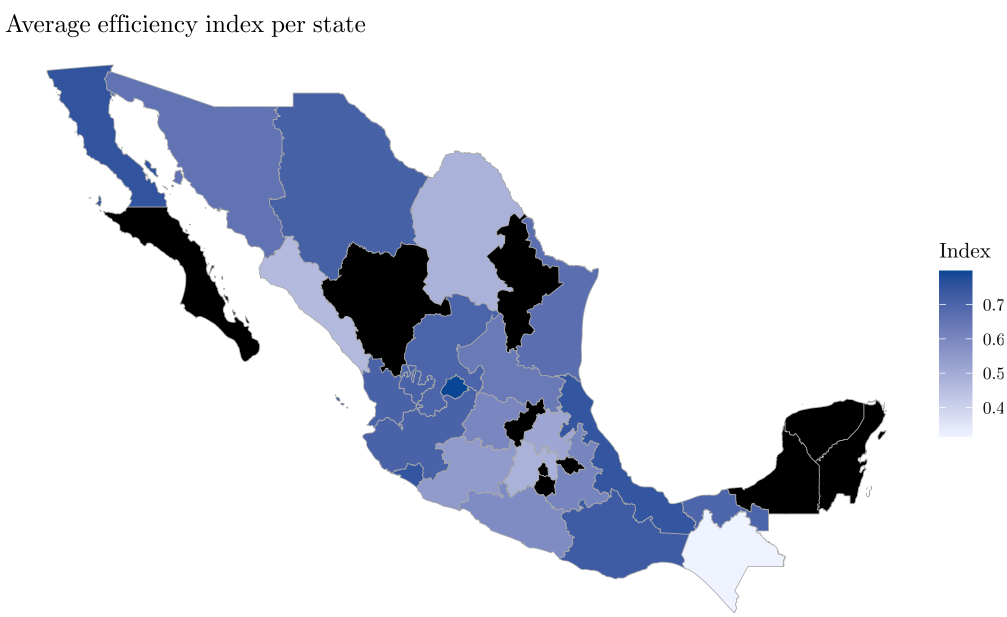
Note: the estimation of the missing rows did not converge. The marginal effects from the specifications with the scaling property are very similar to the estimates from the Truncated-Normal.

As a robustness analysis, I fit two models that have the scaling property, a Truncated-Normal with the scaling property, as specified in Wang and Schmidt (2002), and a Half-Normal model with heteroscedasticity. Nevertheless, in order to achieve convergence, the translog specification of the frontier needs to be restricted.

Table 8 presents the estimates for various restrictions to the translog function and number of inputs used. The results displayed are the marginal effects of the exogenous determinants of inefficiency, the main estimates sought. For comparison purposes, the first two rows display the Truncated-Normal estimates presented in section 4. As can be seen from the analysis, the marginal effects vary little irrespective of the specification. Hence, the preferred model specification is the Truncated-Normal for two reasons: first, it does not require restrictions in the translog function, and second, the marginal effects are similar to the estimates from models with the scaling property.

6.2.6 Distribution of the efficiency index by state

Figure 7: Weighted average efficiency index per state



Note: States in black have no or less than 10 projects in the sample. The efficiency index is estimated by $E[\exp(-\eta_i)|\epsilon_i]$ and ranges from 0 to 1. For interpretation purposes, a value of 0.6 denotes that the minimum cost is 60 percent of the actual cost.

In Figure 7 I aggregate the efficiency results estimated using public auctions. Following Sickles and Zelenyuk (2019), each firm's efficiency is weighted by their relative cost in their respective state. Overall, we can see that the northern states are more efficient, along with the gulf states. The state that fares the worst is Chiapas, in the south, consistent with the fact that it is a region that is hard to access due to the difficult terrain.