# Subcontracting Requirements and the Cost of Government Procurement

Rosa, Benjamin

University of Pennsylvania

6 December 2016

# Subcontracting Requirements and the Cost of Government Procurement

Benjamin V Rosa*

University of Pennsylvania

December 6, 2016

**Abstract**

Government procurement auctions can be subject to policies that specify, as a percentage of the total project, a subcontracting requirement for the utilization of historically disadvantaged firms. This paper studies how these subcontracting policies affect auction outcomes using administrative data from New Mexico's Disadvantaged Business Enterprise (DBE) program. Through the use of a procurement auction model with endogenous subcontracting, I show that subcontracting requirements need not correspond to higher procurement costs – even when disadvantaged firms are more costly. I find small differences in procurement costs as a result of New Mexico's current policy.

## 1 Introduction

Public procurement is a sizable part of US government spending. In 2013, public procurement amounted to 26.1 percent of US government spending and just over 10 percent of US GDP.[1] A portion of that spending is awarded to firms that, because of either size past practices of discrimination, are considered disadvantaged. In particular, the US awarded 23.4 percent of its procurement spending to small businesses in 2013 and 8.61 percent of its procurement spending to small businesses owned by ethnic minorities and women.[2] One method by which these levels of participation are achieved is through the use of subcontracting requirements,

*I would like to thank Mike Abito, Katja Seim, and Hanming Fang, for their guidance and helpful comments. I am grateful to the participants in the Wharton IO seminar and Penn empirical micro and theory lunches for their suggestions, and I would also like to acknowledge David Coriz of the New Mexico Department of Transportation for providing the data.

[1]See the OECD's Government at a Glance 2015 report for more information on other countries.

[2]For a full breakdown of small business spending across federal departments, see the FY 2013 Small Business Goaling Report using the following website: https://www.fpds.gov/fpdsng_cms/index.php/en/reports/63-small-business-goaling-report.html.

which specify a percentage of the total award amount that must be given to preferred firms.[3] The goal of this paper is to understand the mechanisms by which these subcontracting requirements affect procurement auction outcomes.

In adopting subcontracting requirements, governments seek to increase the participation of preferred firms. Unlike other programs with similar participation objectives such as bid discounts that adjust the prices submitted by preferred firms for comparison purposes to make them more competitive and set-aside auctions that only allow preferred firms to compete on certain contracts,[4] subcontracting requirements are unique in that they aim to increase participation through the use of subcontracting. This subcontracting component can require prime contractors to select subcontractors from a common pool of firms, which reduces the private information prime contractors have on their costs of completing a given project.

A notable insight in this paper is that, even when the preferred group of bidders may be more costly, the reduction in private information induced by a common subcontracting component can work to lower the final price received by the government relative to contracts without subcontracting requirements. In particular, I show that the price the government receives for a project depends on the cost of using preferred subcontractors, the fines imposed on firms who miss the subcontracting requirement, and the information rents that accrue to firms with private information on costs. While giving firms incentives to use more preferred subcontractors may increase the cost of completing a given project, the reduction in information rents can work to counteract that cost increase.

The model is then applied to administrative highway procurement auction data from the New Mexico Department of Transportation (NMDOT) in order to evaluate their Disadvantaged Business Enterprise (DBE) program – a program that relies on subcontracting requirements in the form of DBE goals to increase the representation of firms owned and operated by socially and economically disadvantaged individuals.[5] The data set is ideal for this paper in that it provides rich information on the percentage share of construction projects the winning contractor allocates to qualified DBE firms, even when no subcontracting requirement is specified. This richness allows for a systematic analysis of the cost of using DBE firms in procurement.

I find puzzling descriptive evidence on how subcontracting requirements affect auction outcomes. On one hand, the descriptive regressions show that the level of DBE subcontracting requirements is uncorrelated with the winning bids. On the other hand, a similar regression analysis of DBE subcontracting shows that

[3]For example, if a contract valued at $100,000 has a 5 percent subcontracting requirement, then $5,000 of that award must go to preferred firms.

[4]Papers that look at preferences in the form of bid discounts include Krasnokutskaya and Seim (2011), Marion (2007), Rosa (2016), and Hubbard and Paarsch (2009). Papers that explore the effect of set-aside auctions include Athey et al. (2013) and Nakabayashi (2013) .

[5]These individuals include ethnic minorities and women.

higher DBE subcontracting requirements are associated with higher percentage shares of projects awarded to DBE firms. In other words, although DBE subcontracting requirements are effective in increasing DBE participation, they do not change the cost of procurement.

To then explore the different mechanisms that generate these observed bidding and DBE subcontracting patterns, an empirical model of bidding and endogenous subcontracting is developed and estimated with the data. The empirical model provides cost estimates with three separate components: non-DBE costs, DBE costs, and, if a requirement is specified, costs associated with missing the subcontracting requirement. Given the estimated cost components, policy experiments are performed by varying and eliminating the levels of the existing subcontracting requirements. These policy experiments reveal that removing the current DBE subcontracting requirements would increase the average winning bid by only 0.2 percent, reduce the average share of projects completed by DBE firms by 3.4 percent, and increase the average non-DBE firm profits by 0.4 percent.

There are a number of other papers in the literature that also look at subcontracting and how it affects auction outcomes. Jeziorski and Krasnokutskaya (2014) study subcontracting in a dynamic procurement auction and is closely related to the model in this paper. The difference between that paper and this one is that this paper focuses on policies aimed at providing incentives to use a particular type of subcontractor rather than calibrating the dynamic effects of subcontracting. Other studies of subcontracting include Marion (2015a) who looks at the effect of horizontal subcontracting on firm bidding strategies, Miller (2014) who explores the effect of incomplete contracts on subcontracting in public procurement, Nakabayashi and Watanabe (2010) who use laboratory experiments to investigate subcontract auctions, Branzoli and Decarolis (2015) who study how entry and subcontracting choices are affected by different auction formats, Moretti and Valbonesi (2012) who use Italian data to determine the effects of subcontracting by choice as opposed to subcontracting by law, and De Silva et al. (2016) who study how subcontracting affects the survival of firms competing for road construction projects.

The empirical application of this paper to DBE subcontracting requirements also complements the literature on affirmative action policies in government procurement. De Silva et al. (2012) also study DBE subcontracting requirements and find that DBE subcontracting requirements have negligible effects on a firm's cost of completing asphalt projects in Texas. I extend their work by looking at how firms allocate shares of a project to DBE firms and how those decisions are altered when projects specify a positive subcontracting requirement. Marion (2009, 2015b) uses changes in DBE procurement policies to identify the effects of DBE programs on outcomes such as procurement costs and DBE utilization. The approach taken in this paper differs in that this paper uses a model to back out a firm's cost components. The estimated cost components allow for outcome comparisons across a broad range of counterfactual subcontracting policies. Additional studies on the effects of these affirmative action policies include De Silva et al. (2015) who find that affirmative action programs can generate substantial savings for the government and Marion (2011) who studies the effects of affirmative action programs on DBE utilization in California.

The remainder of the paper proceeds as follows. Section 2 describes the procurement process for NMDOT construction contracts and contains details on New Mexico's DBE program. Section 3 presents the theoretical underpinnings of how DBE subcontracting requirements influence the cost structure of bidding firms, and section 4 shows how this theory is estimated from the data. Section 5 contains the descriptive analysis and estimation results, and section 6 uses the estimation results in counterfactual auction simulations. Section 7 concludes.

# 2 New Mexico Highway Procurement

This section describes how the NMDOT awards its construction projects, how the NMDOT's current DBE program operates, and how prime contractors solicit goods and services from DBE subcontractors. The contents of this section provide the institutional details that motivate the modeling choices made in later sections.

## 2.1 Letting

The NMDOT advertises new construction projects four weeks prior to the date of bid opening. As part of the advertising process, each project's main components are summarized in an Invitation for Bids (IFB) document. This document has information on each project's type of work, location, completion deadline, DBE subcontracting requirements (if applicable) and licensing requirements. Interested firms then request the full set of contract documents from the NMDOT and write a proposal for the completion of each project. These proposals contain a plan for completing the required work, which includes a list of all firms used as subcontractors and a price for completing each required task.

In selecting the winning firm, the NMDOT uses a first-price sealed-bid procurement auction format. All interested firms submit their proposals to the NMDOT through a secure website prior to the date of bid opening. On the date of bid opening, all proposals are evaluated by the NMDOT, and the firm who offers the lowest total price on all tasks is selected as the winning firm.[6]

[6]The NMDOT can reject the lowest bid if the lowest bidding firm fails to meet DBE subcontracting requirements or quality

## 2.2 DBE Goals

As a recipient of federal funds, the NMDOT is required to set an overall state goal for the utilization of DBE firms on federally-assisted construction contracts.[7] This state goal is expressed as a percentage of total federal funds awarded to DBE firms, is established on a tri-annual basis, and is typically between 7 and 9 percent. If the NMDOT suspects that DBE utilization will fall short of the overall state goal due to either unanticipated levels of contracts, unforeseen types of contracts, or corrigible deficiencies in the utilization of DBE firms, the NMDOT can assign subcontracting requirements on individual projects which, similar to the state goal, requires that a certain percentage of the project be awarded to DBE firms.

In setting project-specific DBE subcontracting requirements, the NMDOT takes a number of factors into consideration. Elements that affect the assignment of DBE subcontracting requirements include the type of work involved on a project, the location of a project, and the availability of DBE subcontractors to perform the type of work requested on a project. Additionally, only projects with subcontracting opportunities that are estimated to cost more than $\$300,000$ are considered eligible for these requirements.

Once established, a number of incentives are provided to prime contractors to meet a project's DBE subcontracting requirement. Although the requirement is not a quota, contractors who fall short of the requirement incur additional costs in the form of showing satisfactory effort to use DBE firms to the NMDOT as well as a higher probability of having their bid rejected. Moreover, if a prime contractor fails to meet the established DBE subcontracting requirement on a particular project, then that prime contractor can be fined according to the difference between the established goal and the achieved level of DBE participation.

## 2.3 Subcontracting with DBE Firms

New Mexico maintains an online DBE system that is accessible to all governments and contractors. Through this system, prime contractors can find potential DBE subcontractors and request competitive quotes for each part of a project that requires subcontracting. DBE firms selected as subcontractors have their prices count towards the subcontracting requirement provided that they are performing a commercially useful function. Given that the DBE system is accessible to all governments and contractors, it is likely that there are similarities in cost of using DBE subcontractors across firms.[8]

standards. For a more detailed description of how firms are selected and circumstances where a low bid can be rejected, see the NMDOT's Consultant Services Procedures Manual.

[7] For additional information on the NMDOT's DBE program, see the DBE program manual.

[8] Unfortunately, New Mexico does not keep track of the subcontractors used by bidders who do not win. In other states who keep track of DBE commitments on projects with subcontracting requirements, bidders rarely use different firms in satisfying the DBE subcontracting requirement.

In the data, the use of DBE firms as subcontractors is prevalent – even when a project does not have a DBE subcontracting requirement. In particular, 78 percent of all contracts use at least one DBE subcontractor, and 62 percent of contracts without a DBE subcontracting requirement use at least one DBE subcontractor. DBE subcontractors account for a total of 7.1 percent of all contract dollars awarded by the NMDOT.

# 3 Theoretical Model

This section develops a theoretical model that formalizes the different channels through which DBE subcontracting requirements affect bidding and DBE subcontracting decisions. The model is closely related to the subcontracting model proposed by Jeziorski and Krasnokutskaya (2014) but adds a policy that encourages the use of DBE subcontractors.[9]

## 3.1 Environment and Objective Function

Formally, $N$ risk-neutral bidders compete against each other for the rights to complete a single highway construction project. Bidders are ex-ante symmetric in that each bidder draws their non-DBE cost of completing the entire project, $c_i$, independently from the same distribution, $F$, with support on the interval $[\underline{c}, \overline{c}]$, which includes work done by the prime contractor and non-DBE subcontractors. Bidders know the realization of their own cost and the distribution of costs prior to submitting bids.

In addition to the standard setup of a first-price sealed-bid procurement auction, all bidders can choose to subcontract out portions of their projects to DBE firms. That is to say, a project can be partitioned into $T$ tasks. Tasks are indexed by $t \in \{1, 2, \ldots, T\}$, and each task accounts for $\tau_t \in [0, 1]$ percent of the total project. Given a particular task $t$, bidders can choose a share of the task, $s_{i,t} \in [0, 1]$, to give to DBE firms,[10] which reduces the total cost of completing the task from $\tau_t c_i$ to $\tau_t c_i (1 - s_{i,t})$. The cost of using DBE subcontractors on task $t$ is represented by an increasing, convex, and twice continuously differentiable pricing function $P_t : [0, 1] \to \mathbb{R}$, which is known to all bidders and maps the share of the task using DBE subcontractors into a price of using DBE subcontractors.[11] The total cost of task $t$ for DBE

[9] Jeziorski and Krasnokutskaya (2014) also include capacity dynamics and entry in their model. In the data, there is no effect of DBE subcontracting requirements on both the set of planholders (used as a measure of the potential number of bidders) and the fraction of planholders that eventually become bidders. Moreover, different measures of capacity have little influence on both bidding and DBE subcontractor shares. Given that the focus of this paper is on the cost of having DBE subcontracting requirements, this lack of an effect suggests that the analysis should target bidding and subcontracting strategies rather than entry and capacity constraints.

[10] Under this formulation the total share of the project given to DBE firms on task $t$ is $\tau_t s_{i,t}$.

[11] This pricing function represents the prices received by prime contractors from DBE subcontractors on a particular task through the quote solicitation process. Ideally, that market would be modeled separately, and the price would be an endogenous outcome of that market. However, since the data only contains information on the prices listed by DBE subcontracting firms, this paper can only use prices to infer the cost of using DBE subcontractors. For a discussion of the microfoundations of $P_t$, see

subcontracting share $s_{i,t}$ is then given by $\tau_t P_t(s_{i,t})$. One limitation of placing this type of structure on the DBE subcontracting market is that it assumes away any type of private information that a firm may have on using DBE subcontractors. For example, this assumption precludes the possibility that contractors may form relationships with certain DBE subcontracting firms to get discounts on prospective construction projects relative to other firms. Instead, each bidder has access to the same DBE subcontracting technology.

Some highway construction projects offered by the NMDOT are subject to DBE subcontracting requirements. Namely, for every prospective highway construction project, the NMDOT specifies a total share of the project, $\overline{s} \in [0,1]$, to be completed by DBE firms, and this DBE subcontracting requirement is known to all bidders prior to any bidding or DBE subcontracting decisions.[12] The influence of $\overline{s}$ on a bidder's optimal choice of DBE subcontracting and bidding is characterized by a fine function $\varphi : [0,1]^{T+1} \to \mathbb{R}^+$ that is common knowledge and maps a bidder's choice of DBE subcontracting on each task given the DBE subcontracting requirement into a value that can be either zero or positive. For technical reasons, $\varphi$ is assumed to be non-increasing, convex, and continuously differentiable in all of its arguments. When applied, the fine function punishes bidders whose total share of DBE subcontracting lies below the established DBE subcontracting requirement.[13]

In sum, the bidder's optimization problem is given by

$$\max_{\{b_i, \boldsymbol{s}_i\}} \left( b_i - \sum_{t=1}^{T} \tau_t \left( c_i \left(1 - s_{i,t}\right) - P_t\left(s_{i,t}\right)\right) - \varphi\left(\boldsymbol{s}_i; \overline{s}\right) \right) \times \Pr\left(b_i < b_j \forall j \in N \setminus \{i\}\right), \tag{1}$$

where $\boldsymbol{s}_i$ is a vector that collects the bidder's DBE share choices for each task. A strategy in this environment is given by a $T+1$-tuple that consists of a bidding function $b_i : [\underline{c}, \overline{c}] \to \mathbb{R}_+$ and $T$ DBE subcontracting share functions $s_{i,t} : [\underline{c}, \overline{c}] \to [0,1]$, which, for all levels of $\overline{s}$ and for all tasks, maps non-DBE costs into bidding and DBE subcontracting choices. In order to reduce the problem's complexity, this paper focuses on symmetric Nash equilibria in bidding and DBE subcontracting; therefore, the $i$ subscript will be dropped from the bidding and DBE subcontracting strategies without loss of generality.

The DBE subcontracting market introduces a couple of interesting changes into the competitive bidding environment. Perhaps the most salient of these changes is that DBE subcontracting market allows all firms to substitute between completing tasks with their own resources and using DBE subcontractors. This substitution benefits the bidders in that increasing the DBE subcontracting share will lower their non-DBE

the appendix.

[12]A choice of $\overline{s} = 0$ in this environment is analogous to not having a DBE subcontracting requirement.

[13]For example, the NMDOT fines firms whose total share of the project allocated to DBE firms is less than $\overline{s}$; therefore, $\varphi$ will be positive whenever $\sum_{t=1}^{T} \tau_t s_{i,t} - \overline{s} < 0$ and 0 otherwise.

cost of completing the contract; however, making this substitution is costly in that it requires the firm to give up a portion of their profits to their DBE subcontractors. Another notable change is that the DBE subcontracting market generates a common component in the costs of completing a project, since all firms have equal access to DBE subcontracting. This common component lowers the bidder's information rents, leading to a smaller markup relative to a model with no subcontracting.

## 3.2 DBE Subcontracting Strategies

The analysis of bidding and DBE subcontracting behavior begins by finding the optimal DBE subcontracting share given a cost realization and a DBE subcontracting requirement. The first-order conditions can be used to characterize an optimal DBE subcontracting share $s_t(c_i;\bar{s})$ that does not occur at the boundary.[14] Taking these first-order conditions yields

$$c_i = P_t'(s_{i,t}) + \frac{\varphi_{s_t}(\boldsymbol{s}_i;\bar{s})}{\tau_t}. \tag{2}$$

For bidders whose optimal choice is to never use DBE subcontractors on a particular task, the following condition must hold:

$$c_i < P_t'(0) + \frac{\varphi_{s_t}(s_{i,1},\ldots,s_{i,t-1},0,s_{i,t+1},\ldots,s_{i,T};\bar{s})}{\tau_t}. \tag{3}$$

Likewise, bidders whose optimal choice is to subcontract the entire task to DBE firms must have the following condition hold:

$$c_i > P_t'(1) + \frac{\varphi_{s_t}(s_{i,1},\ldots,s_{i,t-1},1,s_{i,t+1},\ldots,s_{i,T};\bar{s})}{\tau_t}. \tag{4}$$

There are a couple of characteristics of optimal DBE subcontracting that are worth mentioning. Similar to Jeziorski and Krasnokutskaya (2014), the optimal DBE subcontracting decision does not depend on the probability of winning the auction. Intuitively, the benefits and costs from subcontracting only influence a bidder's objective function through the payoff conditional on winning while leaving the probability of winning unchanged. Bidders therefore do not take the probability of winning into account when deciding how to use DBE subcontractors. Another characteristic of optimal DBE subcontracting is that the optimal share does not depend on the bid. In this sense, the optimal decisions of a bidder can be reinterpreted as follows: upon the realization of $c_i$, bidders first determine how much of the project to subcontract out to DBE firms on each task; then, bidders determine how much to bid given their optimal choice of $\boldsymbol{s}_i$.[15]

[14] In addition to the first-order conditions, the second-order conditions must also hold for the solution to be a maximum. The details of the second order conditions can be found in the appendix.

[15] Another property of optimal DBE subcontracting is that the total share of work given to DBE firms is non-decreasing in $c_i$.

Before moving into the bidding strategies, it is also worth observing the effect of having DBE subcontracting requirements on DBE subcontracting decisions. Assuming an interior choice of $s_t(c_i;\bar{s})$, assigning a positive DBE subcontracting requirement to a project only affects the DBE subcontractor choice through the slope of the fine function rather than its value. From a policy prospective, bidders are more likely to change their subcontracting behavior if $\varphi$ changes rapidly in $s_t$, implying that policies that impose larger marginal fines for missing the DBE subcontracting requirement are more effective in changing in the optimal DBE subcontracting shares.

### 3.3 Bidding Strategies

In addition to a DBE subcontracting share, bidders must also decide on how to submit a bid. To understand this decision-making process, it is useful to first distinguish the firm's cost of completing the project from the effective cost of completing the project, which takes into account the firm's cost, the firm's optimal DBE subcontracting decisions, and any fines.[16] Similar to Jeziorski and Krasnokutskaya (2014), define $\phi(c_i;\bar{s}) = \sum_{t=1}^{T} \tau_t \left(c_i \left(1 - s_t(c_i;\bar{s})\right) + P_t\left(s_t(c_i;\bar{s})\right)\right) + \varphi\left(\boldsymbol{s}(c_i;\bar{s});\bar{s}\right)$ as the firm's effective cost of completing a construction project. Substituting $\phi$ into equation 1 and removing the optimization over $\boldsymbol{s}_i$ reduces the problem to a first-price sealed-bid procurement auction where bidders draw an effective cost rather than a non-DBE cost. This transformed optimization problem together with boundary condition $b\left(\bar{\phi}\right) = \bar{\phi}$ has a unique solution that is increasing in $\phi$ using arguments from Reny and Zamir (2004), Athey (2001) and Lebrun (2006).[17] As a result, the remainder of this paper will focus on symmetric bidding strategies that are increasing in $\phi$.

There is a tight relationship between a firm's effective cost of completing a project and a firm's non-DBE cost. In particular, note that

$$\phi'(c_i;\bar{s}) = \sum_{t=1}^{T} \tau_t \left(1 - s_t(c_i;\bar{s})\right) \geq 0, \tag{5}$$

where the above inequality uses the first-order conditions on optimal DBE subcontracting to eliminate the extra terms in the derivative. Equation 5 demonstrates that the effective cost is increasing in $c_i$ whenever

This property can potentially be rejected by the data if bidders who submit higher bids choose lower DBE subcontracting shares since it will be shown that bids are also increasing in $c_i$ for $s_t(c_i;\bar{s}) \in [0,1)$. Although the data cannot directly address this issue, this property can be tested by using bids as a proxy for costs in DBE subcontracting regressions. When included in a DBE subcontracting regression, the coefficient on the submitted bids is positive and significant, suggesting that DBE subcontracting shares are associated with higher non-DBE costs.

[16] Recall that optimal subcontracting can be calculated independently of the bid. Therefore, the effective cost can be found prior to bidding and can be substituted in the objective function, obviating the need to optimize over $s_{i,t}$.

[17] Observe that $\bar{\phi} = \sum_{t=1}^{T} \tau_t P_t(1) + \varphi(\mathbf{1};\bar{s})$ is the cost of subcontracting the entire project to DBE firms, where $\mathbf{1}$ is a vector of ones of length $T$. This observation comes from the previous result that the optimal DBE subcontracting share is increasing in $c_i$.

$s_t(c_i;\overline{s}) \in [0,1)$ for at least one task and flat whenever $s_t(c_i;\overline{s}) = 1$ for all tasks, which is intuitive since firms with lower non-DBE costs should also have lower effective costs unless they subcontract the entire project to DBE firms. Furthermore, this relationship implies that the optimal bidding function is increasing in $c_i$ except when $s_t(c_i;\overline{s}) = 1$ for all tasks.

Using an envelope theorem argument[18] and the relationship derived from equation 5, an expression for the optimal bidding function can be derived in terms of non-DBE costs. This expression is given below, with the details of its derivation contained in the appendix.[19]

**Proposition 1.** *The optimal bid function is given by*

$$\begin{aligned} b(c_i;\overline{s}) &= \underbrace{\sum_{t=1}^{T} \tau_t \left(1 - s_t(c_i;\overline{s})\right) \frac{\int_{c_i}^{\overline{c}} \left(1 - F(\tilde{c})\right)^{N-1} d\tilde{c}}{\left(1 - F(c_i)\right)^{N-1}}}_{\text{markup}} \\ &+ \underbrace{\sum_{t=1}^{T} \tau_t \left(P_t\left(s_t(c_i;\overline{s})\right) + c_i\left(1 - s_t(c_i;\overline{s})\right)\right) + \varphi\left(\boldsymbol{s}(c_i;\overline{s});\overline{s}\right)}_{\text{effective cost}} \end{aligned} \tag{6}$$

There are a couple of key features of this bidding function that are driven by DBE subcontracting and the fine function. In particular, the optimal bid function can be interpreted as a strategic markup over effective costs. An increase in DBE subcontracting on any one task necessarily reduces a bidder's strategic markup in addition to a reduction in total non-DBE costs. Also, bidding is directly affected by the level of the fine function, implying that the degree to which the NMDOT punishes deviations from the subcontracting requirement will be reflected in the observed bids rather than in the subcontracting decisions.

## 3.4 The Role of DBE Subcontracting Requirements

Given these features of the optimal bid and DBE subcontracting functions, there are a couple of changes induced by imposing DBE subcontracting requirements. These changes are summarized in the next proposition and corollary, with the proofs of each statement given in the appendix.

**Proposition 2.** *For a given task $t$, if $s_t(c_i;0) \neq s_t(c_i;\overline{s})$, then $s_t(c_i;0) < s_t(c_i;\overline{s})$.*

[18] See Milgrom and Segal (2002).

[19] The NMDOT does not use reservation prices in its procurement auctions, so the model does not include a reservation price. The absence of reservation prices can potentially be problematic, though: when there is only one bidder in an auction, the lack of competition could give rise to unusually high equilibrium bids. To address this problem, this paper follows Li and Zheng (2009) in assuming that auctions with one bidder face additional competition from the NMDOT in the form of an additional bidder during the structural estimation and counterfactual policy simulations. This assumption approximates the right of the NMDOT to reject high winning bids. In the data, only 4.6 percent of all auctions have one bidder.

Proposition 2 essentially says that on tasks where the policy can affect DBE subcontracting, subcontracting requirements will increase the share of work given to DBE subcontractors. The idea behind the proof is that prime contractors want to increase the share of work given to DBE firms to avoid incurring any fines. Therefore, prime contractors will increase the share of work given to DBE firms on tasks where using DBE subcontractors is sufficiently low priced.

**Corollary 1.** *If $s_t(c_i; 0) < s_t(c_i; \overline{s})$ on at least one task, then the effect of DBE subcontracting requirements on bids is ambiguous.*

The intuition behind the proof of corollary 1 is that there are four channels through which an increased DBE share on a particular task can affect bids: through a reduction in the markup; through a reduction in the total non-DBE costs; through an increase in the total cost of using DBE firms; and through the value of the fine function. Given the assumptions on $s_t(c_i; 0)$ and $s_t(c_i; \overline{s})$, DBE subcontracting requirements will increase the total share of work allocated to DBE firms on at least one task, but that increase can map to a range of different effects on bidding – each depending on the relative strength of the four aforementioned channels. The model is therefore malleable to many different explanations of how DBE subcontracting requirements affect bidding.

# 4 Empirical Model and Estimation

Although the theoretical model is flexible in describing the different avenues through which DBE subcontracting requirements can affect bidding and subcontracting, it cannot be bought to the data without additional assumptions. This section outlines the assumptions used to estimate the theoretical model and provides a description of the estimation procedure. First, the simplifying and parametric assumptions underlying the empirical model are stated; then, the estimation procedure used to generate the parameter estimates is described. Finally, the sources of variation in the data that aid in identifying the parameters are discussed.

## 4.1 Simplifying Assumptions

The data is limited in that it does not have a complete description of the tasks required to complete each construction project. Moreover, each task in the data would require a different price function estimate, which would be impractical with a large number of possible tasks. As a result, the empirical model proceeds under the assumption that each project can be combined into one aggregate task. Under this assumption, firms choose a total share of the project to allocate to DBE firms ($s_i$) and face an aggregate DBE pricing function

$(P(\cdot))$. The first order conditions for optimal DBE subcontracting of this simplified model is then given by

$$c_i = P'(s_i) + \varphi'(s_i; \overline{s}), \tag{7}$$

while the optimal bid function of the simplified model is then given by

$$\begin{array}{rcc} b(c_i; \overline{s}) & = & (1 - s(c_i; \overline{s})) \frac{\int_{c_i}^{\overline{c}} (1-F(\tilde{c}))^{N-1} d\tilde{c}}{(1-F(c_i))^{N-1}} \\ & + & P(s(c_i; \overline{s})) + c_i (1 - s(c_i; \overline{s})) + \varphi(s(c_i; \overline{s}); \overline{s}) \end{array}. \tag{8}$$

## 4.2 Parametric Assumptions

The simplified theoretical model is estimated by placing parametric assumptions on the distribution of non-DBE costs, the DBE pricing function, and the fine function. The extent to which these distributions and functions can be parameterized is closely related to the observable project characteristics in the data. Consequently, a project, indexed by $w$, is assumed to be uniquely determined by the vector $(\boldsymbol{x}_w, \boldsymbol{z}_w, \overline{s}_w, u_w, N_w)$, where $\overline{s}_w$ is the DBE subcontracting requirement, $\boldsymbol{x}_w$ and $\boldsymbol{z}_w$ are potentially overlapping vectors of the remaining project-level observables that affect non-DBE costs and DBE pricing respectively, $u_w$ is a project characteristic unobservable by the econometrician but observable to the bidders that affects DBE pricing, and $N_w$ is the number of bidders on a project.

Here, the project characteristic $u_w$ represents unobserved conditions in the DBE subcontracting market such as the availability of DBE firms to act as subcontractors and the concentration of DBE firms in a required task. Since the NMDOT may have extra information on these unobservable characteristics when establishing a DBE subcontracting requirement, the realization of $u_w$ is allowed to depend on $\overline{s}_w$. Let $DBE\,req = \overline{s}_w \times 100$. The distribution of $u_w$ is then assumed to follow a gamma distribution with a shape parameter of 1 and a scale parameter of $\sigma_u = \exp(\sigma_{u1} + \sigma_{u2} DBE\,req)$.

Similarly, there are a few assumptions made on the non-DBE cost distribution in order for the empirical model to be consistent with the theory. To keep costs positive, non-DBE costs are assumed to follow a truncated log normal distribution:

$$c_i \sim \mathcal{TLN}\left(\psi' \boldsymbol{x}_w, \sigma_c^2, \overline{c}_w \mid \boldsymbol{x}_w\right),$$

where $\psi$ is a vector of structural parameters that shift the cost distribution and $\overline{c}_w$ is the project-specific upper bound on the cost distribution.[20] The variable $\overline{c}_w$ is used to get the upper limit of integration when solving for the equilibrium bids using equation 8 and is constructed using the project cost estimates in relation to the highest bid in the sample. In particular, let $\hat{x}_w \in \boldsymbol{x}_w$ be the estimated value of any given project in the sample, and suppose $k$ is the maximum of the ratio of bids relative to the engineer's estimate $\left(k = \max\left\{\frac{b_{iw}}{\hat{x}_w}\right\}\right)$. Then $\overline{c}_w = k\hat{x}_w$.[21]

For the pricing and fine functions, parametric functional forms are implemented that are very similar to those used by Jeziorski and Krasnokutskaya (2014). In particular, the DBE pricing function and fine function are assumed to take the following functional forms:

$$P(s_i) = \left(\alpha_0 + \alpha_1 s_i + \alpha_2 \frac{s_i}{1-s_i} + \alpha_3' \boldsymbol{z}_w + u_w\right) s_i \hat{x} \tag{9}$$

$$\varphi(s_i; \overline{s}_w) = \begin{cases} \gamma (s_i - \overline{s})^2 \hat{x} & \text{if } s_i < \overline{s} \\ 0, & \text{if } s_i \geq \overline{s} \end{cases} \tag{10}$$

The hyperbolic term in equation 9 prevents firms from subcontracting entire projects to DBE firms.[22] The multiplication by $\hat{x}$ in $P$ and $\varphi$ is used to make sure the problem scales properly since projects vary in size, while the multiplication by $s_i$ in $P$ ensures that a firm that allocates none of the project to DBE firms does not have a cost of using DBE subcontractors. Also, the piecewise functional form of equation 10 is used so that only firms who fail to meet the DBE subcontracting will ever be fined. It is important to note, however, that the parameter values must be constrained for the problem to have desirable properties such as an interior maximum, an increasing price function, and a non-increasing fine function for different parameter guesses. These constraints are presented in the estimation appendix.

## 4.3 Estimation

Given these parametric assumptions, the empirical model generates unique solutions for DBE subcontracting shares and equilibrium bids. These predictions are matched to the observed DBE subcontracting and winning bids in the data using indirect inference.[23] To outline this matching process, two auxiliary models are first

[20]Given that $c_i$ is log normal, there is automatically a lower bound at 0.

[21]Note that this upper limit is only valid if the observation in which this ratio is maximized has no share of the project allocated to DBE firms since the boundary condition on bids is in terms of effective costs rather than non-DBE costs. While the share of the project allocated to DBE firms is not observed for losing bidders, the winning bidder in the auction used to set $k$ has a DBE share of 0 which makes this approximation plausible.

[22]In the data no firms select a DBE share of 100%, so this functional form is chosen to mirror that empirical fact.

[23]Indirect inference was first used by Smith (1993) in a time-series setting and extended by Gourieroux et al. (1993) to a more general form. Methods from this extended version are used in the estimation of the empirical model.

estimated from the data: an ordinary least squares (OLS) model of the log-winning bids and an OLS model of the winning bidder's DBE subcontracting share. Then, $N_w$ costs are simulated for each auction using a guess for the structural parameters of the cost distribution, and the lowest of the $N_w$ costs is taken to be the cost of the winning bidder.[24] Let $W$ denote the total number of auctions observed in the data and $H$ the total number of simulations. Then a total of $WH$ costs are selected from the $\sum_w N_w H$ simulated costs. Next, the equilibrium winning bids and DBE subcontracting decisions are calculated using the theoretical results in conjunction with the empirical model, the pricing function parameters, the fine function parameters, and the simulated costs from the previous step. Lastly, a new auxiliary model is estimated using the $WH$ simulated observations, and the distance between the auxiliary model estimates and the simulated auxiliary model estimates are minimized using an optimization routine.[25]

In minimizing the distance between the auxiliary model parameters from the data and the auxiliary model parameters generated from the structural parameters, a Wald criterion function is employed. In particular, the indirect inference structural parameter estimates, $\theta$, are a solution to the following criterion:

$$\min_{\theta \in \Theta} \left[\hat{\beta}_W - \tilde{\beta}_{HW}(\theta)\right]' \hat{\Omega}_W \left[\hat{\beta}_W - \tilde{\beta}_{HW}(\theta)\right],$$

where $\hat{\beta}_W$ are the auxiliary model parameters estimated from the data, $\tilde{\beta}_{HW}(\theta)$ are the auxiliary model parameters estimated from the structural parameters, and $\hat{\Omega}_W$ is some positive definite weighting matrix.[26] The standard errors are calculated using the asymptotic distribution of the indirect inference estimator.

## 4.4 Parametric Identification

Given that this model differs from the standard first-price sealed-bid procurement auction in several dimensions, it is useful to mention the variation in the data that identifies the structural model parameters. In the model there are several primitives that need to be identified from the data. These primitives are the DBE pricing function, the fine function, and the distribution of non-DBE costs.

The non-DBE cost distribution parameters are separately identified from the DBE pricing function and fine function parameters through the variation in bids on contracts with no DBE subcontracting share and

[24] Recall that bids are increasing in costs, so the lowest of the cost draws will correspond to the winning bidder.

[25] Note that this estimation routine directly estimates the costs rather than relying on indirect methods used in Guerre, Perrigne, and Vuong (2000) and Jofre-Bonet and Pesendorfer (2003). While indirect methods are faster than the direct method used in this paper, the existence of corner solutions, particularly when $s(c_i) = 0$, can present problems in estimation with indirect estimators. To my knowledge, the model can only be estimated indirectly by assuming the first-order conditions for subcontracting exactly hold on the corner. Given that there is a non-trivial amount of observations with $s(c_i) = 0$ in the data, these indirect estimators are avoided.

[26] In estimation, the optimal weight matrix is used as the weighting matrix.

no DBE subcontracting requirement. Intuitively, the equilibrium bid function does not depend on the DBE pricing and fine functions when the optimal DBE subcontracting share and subcontracting requirement are zero; therefore, any variation in bids is due to variation in non-DBE costs. The parameter of the fine function is separately identified from the parameters of the DBE pricing function through prime contractors who miss the DBE subcontracting requirement. The idea here is that fines only affect bids and subcontracting when a prime contractor fails to reach a given requirement, so any differences in bidding and subcontracting between prime contractors who meet and do not meet the requirement are attributed to the fine function. Note that the distribution of the unobserved DBE pricing component is identified through variation in bidding and subcontracting from observationally equivalent projects that are not due to differences in non-DBE costs, since these variations must come from latent variables.

# 5 Empirical Analysis

In this section, the empirical analysis is performed on the procurement data from New Mexico. The analysis begins with a description of the data and variables. Summary statistics and descriptive regressions are then presented to highlight bidding and DBE subcontracting patterns present in the data. Finally, the structural parameter estimates from the empirical model are provided, followed by a discussion model fit.

## 5.1 Data Description and Variables

The data is composed of federally-funded highway construction contracts issued by the NMDOT from 2008 until 2014 for the maintenance and construction of transportation systems. In order to be consistent with the model, the sample does not include contracts won by DBE prime contractors.[27] The subcontracting portion of the data is taken from administrative records from New Mexico's SHARE system. The SHARE data is part of New Mexico's state-wide accounting system and tracks all of the transactions between the NMDOT and the contractors who are ultimately awarded projects using federal aid. This data contains information on the subcontractors used in each construction project, including the subcontractor's DBE status and the amount of money allocated to each subcontractor.

The SHARE data is augmented with data on contract characteristics. In particular, the competition each winning contractor faces in terms of the actual number of bidders and the number of bidders who request information about each project, the advertised DBE subcontracting requirement, the type of work necessary

[27] The model assumes that the prime contractor is not a DBE firm, which is the case for the majority of contracts awarded by the NMDOT. Moreover, prime DBE contractors are not affected by DBE subcontracting requirements since the prime contractor must perform most of the work.

to complete each project, the estimated cost of completing each project, and the expected number of days needed to complete each project are observed. This data is gathered from publicly-available NMDOT bidding records, which includes the IFB documents the NMDOT uses to advertise their projects and spreadsheets containing each project's received bids and eligible bidders.

The particular set of variables observed in the full data set are defined as follows. *DBE share* is the percentage share of the total project awarded to DBE subcontractors. *Engineer's estimate* is an estimate of a project's costs that is provided by engineers from the NMDOT. *Winning bid* is the bid that ultimately wins the procurement auction. *Subprojects* are smaller portions of a larger project that are specified in the IFB documents and are used as a measure of how easily a contract can use subcontractors.[28] *Working days* are the number of days a given project is expected to take to complete, and *licenses* refers to the number of separate license classifications required to complete the project. *Length* indicates the length of the construction project, and *DBE req* is the level of the DBE subcontracting requirement. *Planholders* refers to the number of firms requesting documents necessary to submit a bid, and *federal highway* and *urban* are indicator variables that take on a value of one if a project is located on a federal highway or an urban county respectively.

Additional observables are used to distinguish a project's location and the type of work requested for each project. *District* is a variable that indicates a project's administrative district. In New Mexico, there are a total of six mutually-exclusive districts – each serving a different region of the state. The type of work requested for each project is separated into six different categories: road work, bridge work, lighting, safety work, stockpiling, and other. The other category is used as the reference class.

### 5.2 Summary Statistics

Table 1 presents the summary statistics from the entire sample of NMDOT highway construction contracts. Projects are divided into four categories: projects with subcontracting requirements, projects without subcontracting requirements, projects eligible for subcontracting requirements yet do not have any, and the entire sample of projects. Recall that New Mexico considers all projects estimated to cost more than $\$300,000$ eligible for subcontracting requirements.

Table 1 indicates a couple of differences across projects with and without subcontracting requirements. Projects with subcontracting requirements have, on average, 2.4 more subprojects and are estimated to cost $1.4 million more than eligible projects without subcontracting requirements. Also, projects with subcon-

[28] See the appendix for an example of subprojects.

Table 1: Summary Statistics

| | With Req. | | W/o Req. | | W/o Req. & Eligible | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Eng. Estimate (1000s) | 5530.86 | 6682.41 | 3817.25 | 6781.04 | 4120.84 | 6975.37 | 4618.99 | 6780.67 |
| Winning Bid (1000s) | 5256.19 | 6843.40 | 3438.49 | 5858.68 | 3712.46 | 6019.81 | 4288.93 | 6394.94 |
| Bidders | 4.64 | 1.94 | 4.08 | 1.93 | 4.14 | 1.96 | 4.34 | 1.95 |
| Subprojects | 9.83 | 5.12 | 7.21 | 4.70 | 7.47 | 4.78 | 8.43 | 5.07 |
| DBE Share (%) | 9.15 | 7.20 | 4.25 | 6.29 | 4.30 | 5.77 | 6.54 | 7.15 |
| DBE Req. (%) | 4.20 | 1.91 | 0.00 | 0.00 | 0.00 | 0.00 | 1.97 | 2.47 |
| Share-Req. Gap (%) | 4.95 | 6.91 | 4.25 | 6.29 | 4.30 | 5.77 | 4.58 | 6.59 |
| Comply if Req. | 0.91 | 0.29 | | | | | 0.91 | 0.29 |
| Number of Contracts | 182 | | 207 | | 191 | | 389 | |

tracting requirements allocate 4.9 percentage points more to DBE subcontractors relative to eligible projects without subcontracting requirements. Many of the prime contractors on projects with requirements comply with the requirement, allocating an average of 5.0 percentage points more than the required amount to DBE firms.

## 5.3 Descriptive Regressions

In order to explore bidding patterns in the data, OLS regressions of the log-winning bids are run on the covariates collected from the NMDOT bidding data. Table 2 reports regression coefficients. Here, the main parameter of interest is the coefficient on the DBE requirement variable as it shows the correlation between the winning bids and the DBE subcontracting requirement. Column (1) only controls for the variable of interest and the engineer's estimate. Column (2) includes additional controls for complexity (length, subprojects, working days and licensing requirements) and the type of work requested. The competitive bidding environment is captured in the second column by the number of planholders and the number of bidders, while other control variables such as administrative district (not displayed in the regression tables), whether a project is in an urban or rural county, and whether the project takes place on a federal highway are included to account for a project's proposed location. Column (3) adds month and year fixed effects as a control for seasonality. These regression specifications are repeated in columns (4) - (6) for a sample limited to projects eligible for DBE subcontracting requirements.

The regressions indicate that the winning bids are practically uncorrelated with the usage of DBE subcontracting requirements: across all specifications, the coefficient on the DBE requirement variable is small and statistically insignificant.[29] These results suggest that DBE subcontracting requirements are not associated

[29]It is important to note that these coefficients will be biased if there are unobservable factors that affect both bidding (later,

Table 2: OLS Regression of the Winning Bids

| | *Dependent variable:* | | | | | |
|---|---|---|---|---|---|---|
| | log(Winning Bid) | | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| log(Engineer's Estimate) | 0.982*** | 0.938*** | 0.938*** | 0.971*** | 0.926*** | 0.927*** |
| | (0.009) | (0.020) | (0.020) | (0.009) | (0.021) | (0.021) |
| DBE Req (%) | −0.002 | 0.002 | 0.002 | −0.002 | 0.001 | 0.001 |
| | (0.003) | (0.004) | (0.004) | (0.003) | (0.004) | (0.003) |
| log(Length + 1) | | 0.021 | 0.026* | | 0.019 | 0.023* |
| | | (0.014) | (0.014) | | (0.014) | (0.013) |
| log(Planholders) | | −0.050 | 0.014 | | −0.064 | −0.031 |
| | | (0.044) | (0.054) | | (0.043) | (0.047) |
| log(Subprojects) | | 0.079*** | 0.068** | | 0.083*** | 0.082*** |
| | | (0.026) | (0.027) | | (0.025) | (0.024) |
| Number of Licenses Required | | 0.038** | 0.032* | | 0.043** | 0.039** |
| | | (0.018) | (0.018) | | (0.018) | (0.018) |
| log(Working Days) | | 0.018 | 0.012 | | 0.017 | 0.009 |
| | | (0.025) | (0.024) | | (0.026) | (0.025) |
| Bidders | | −0.024*** | −0.017*** | | −0.024*** | −0.017*** |
| | | (0.005) | (0.005) | | (0.005) | (0.005) |
| Federal Highway | | 0.006 | 0.001 | | 0.008 | 0.004 |
| | | (0.021) | (0.021) | | (0.020) | (0.021) |
| Urban | | −0.054* | −0.056* | | −0.052* | −0.048 |
| | | (0.030) | (0.029) | | (0.030) | (0.029) |
| Work Type/District Controls | | X | X | | X | X |
| Month/Year FEs | | | X | | | X |
| Observations | 389 | 389 | 389 | 373 | 373 | 373 |
| Adjusted $R^2$ | 0.976 | 0.980 | 0.982 | 0.973 | 0.979 | 0.981 |

*Note:* *p<0.1; **p<0.05; ***p<0.01
Descriptive OLS regressions of the winning bid on project-level observables. Columns (1)-(3) use all projects, while columns (4)-(6) only use projects eligible for subcontracting requirements. Standard errors are robust.

with the ultimate cost of procurement and is comparable to De Silva et al. (2012) who find a lack of an effect of DBE subcontracting requirements on asphalt procurement auctions in Texas.

Given that winning bids and DBE subcontracting requirements are uncorrelated, it is reasonable to question whether DBE subcontracting requirements have any impact on DBE firm participation. To address this question, a regression analysis of the percentage of projects allocated to DBE firms by winning contractors is conducted using the same six regression specifications as the winning bid regressions. The results are reported in table 3.

Unlike the winning bid regressions, DBE subcontracting requirements have a positive and significant correlation with DBE participation. Increasing the DBE subcontracting requirement by one percent increases the share of DBE firms used as subcontractors by about one percent over the different regression specifications. These results suggest that the DBE subcontracting requirements, although uncorrelated with the winning

DBE subcontracting decisions) and the decision of whether to include DBE subcontracting requirements on a particular project. While the control variables account for many of the factors used in setting DBE subcontracting requirements, the possibility of biased regression estimates still remains. The empirical model explicitly accounts for this type of bias by allowing for the subcontracting requirements to be related to unobservable factors that influence the price of using DBE subcontractors.

Table 3: OLS Regressions of the DBE Shares

| | *Dependent variable:* | | | | | |
|---|---|---|---|---|---|---|
| | DBE Share (%) | | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| log(Engineer's Estimate) | 0.240 | −0.304 | −0.353 | 0.308 | −0.204 | −0.139 |
| | (0.351) | (0.581) | (0.622) | (0.306) | (0.559) | (0.530) |
| DBE Req (%) | 1.108*** | 0.984*** | 1.016*** | 1.101*** | 0.971*** | 0.922*** |
| | (0.142) | (0.152) | (0.183) | (0.142) | (0.156) | (0.182) |
| log(Length + 1) | | −0.116 | 0.017 | | −0.298 | −0.205 |
| | | (0.506) | (0.511) | | (0.460) | (0.459) |
| log(Planholders) | | −0.567 | 1.650 | | −1.190 | 1.540 |
| | | (1.795) | (1.940) | | (1.626) | (1.952) |
| log(Subprojects) | | 1.946** | 1.412 | | 2.209** | 1.847** |
| | | (0.840) | (0.870) | | (0.865) | (0.869) |
| Number of Licenses Required | | 1.509* | 1.758* | | 1.060 | 1.052 |
| | | (0.905) | (0.929) | | (0.826) | (0.785) |
| log(Working Days) | | −0.407 | −0.606 | | −0.280 | −0.533 |
| | | (0.608) | (0.603) | | (0.610) | (0.608) |
| Bidders | | −0.076 | −0.060 | | 0.003 | −0.011 |
| | | (0.213) | (0.215) | | (0.197) | (0.215) |
| Federal Highway | | −0.133 | −0.237 | | 0.038 | 0.009 |
| | | (0.701) | (0.686) | | (0.698) | (0.688) |
| Urban | | 2.055** | 1.903** | | 1.847** | 1.549* |
| | | (0.934) | (0.970) | | (0.841) | (0.871) |
| Work Type/District Controls | | X | X | | X | X |
| Month/Year FEs | | | X | | | X |
| Observations | 389 | 389 | 389 | 373 | 373 | 373 |
| Adjusted $R^2$ | 0.152 | 0.216 | 0.229 | 0.162 | 0.217 | 0.235 |

*Note:* *p<0.1; **p<0.05; ***p<0.01

Descriptive OLS regressions of the DBE subcontractor share on project-level observables. Columns (1)-(3) use all projects, while columns (4)-(6) only use projects eligible for subcontracting requirements. Standard errors are robust.

bids, are associated with their goal of increasing the participation of DBE firms.

### Evidence that Higher DBE Shares Reduce Firm Markups

The final piece of descriptive evidence presented in this subsection addresses how the share of work allocated to DBE firms relates to non-DBE firm markups. In the model, increasing the number of competing bidders affects bids by reducing non-DBE firm markups. The share of work given to DBE subcontractors also reduces non-DBE firm markups, so the reduction in bids due to the amount of work assigned to DBE firms should be attenuated by the number of competing bidders. In the reduced form, this attenuation effect will appear in the coefficient of an interaction term between the number of bidders and the share of work allocated to DBE firms; a positive coefficient suggests that the share of work given to DBE firms reduces the loss in markups due to an increased number of competitors.

To investigate whether there is evidence of this attenuation effect in the data, regressions of the log-winning bid are performed on the project-level covariates with an additional control for the DBE share and

Table 4: OLS Regressions of the Share-Bidder Interaction

| | *Dependent variable:* | | | | | |
|---|---|---|---|---|---|---|
| | log(Winning Bid) | | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| log(Engineer's Estimate) | 0.986*** | 0.939*** | 0.939*** | 0.975*** | 0.928*** | 0.929*** |
| | (0.008) | (0.020) | (0.020) | (0.008) | (0.021) | (0.021) |
| DBE Share (%) | −0.002 | −0.002 | −0.003 | −0.003 | −0.004 | −0.004* |
| | (0.003) | (0.003) | (0.002) | (0.003) | (0.003) | (0.002) |
| Bidders | −0.038*** | −0.031*** | −0.025*** | −0.041*** | −0.034*** | −0.026*** |
| | (0.007) | (0.007) | (0.006) | (0.007) | (0.007) | (0.006) |
| DBE Share × Bidders | 0.001** | 0.001* | 0.001** | 0.001** | 0.001** | 0.001*** |
| | (0.001) | (0.001) | (0.0005) | (0.001) | (0.001) | (0.0005) |
| Project/Work Type/District Controls | | X | X | | X | X |
| Month/Year FEs | | | X | | | X |
| Observations | 389 | 389 | 389 | 373 | 373 | 373 |
| Adjusted $R^2$ | 0.979 | 0.980 | 0.982 | 0.977 | 0.979 | 0.981 |

*Note:* *p<0.1; **p<0.05; ***p<0.01

Descriptive OLS regressions of the winning bid on project-level observables with bidder-share interaction terms. Columns (1)-(3) use all projects, while columns (4)-(6) only use projects eligible for subcontracting requirements. Standard errors are robust.

an interaction term between the the DBE share and the number of bidders. The regression specifications follow the same format as the the winning bid regressions, and the coefficient of interest here is the coefficient on the interaction term.

The results for the entire sample of winning bids and the winning bids on projects eligible for DBE subcontracting requirements are presented in table 4. Consistent with the model, there is a positive and statistically significant coefficient on the interaction term across all regression specifications. Taken together with the negative and statistically significant coefficient on the number of bidders, these regressions suggest that DBE utilization can work to reduce non-DBE firm markups.

To summarize the main results, the descriptive regressions provide evidence for how DBE subcontracting requirements affect bidding, how DBE subcontracting requirements affect the amount of work subcontracted to DBE firms, and how the share of work given to DBE subcontractors affects firm markups. Winning bids are found to be uncorrelated with DBE subcontracting requirements, and DBE subcontracting requirements are found to increase the participation of DBE firms. These two empirical facts appear to be contradictory given the expected increase in costs associated with using disadvantaged firms, motivating the need to investigate the channels proposed in the theoretical model. Finally, evidence that the share of work given to DBE subcontractors reduces firm markups is found in the data, which is consistent with the implications of the model.

## 5.4 Structural Parameter Estimates

Next, the parameters from the empirical model are estimated. The distribution of log-non-DBE costs are assumed to be linear in a project's engineer's estimate, complexity, location, and type of work required with a constant variance. The parameters of the DBE pricing function follow the functional form outlined in equation 9, with the distribution of the unobserved price shock allowed to depend on the DBE subcontracting requirement and a control for the number of subprojects. The parameters of the fine function follow equation 10. Since the subcontracting requirement can affect the realization of the unobserved pricing component, the estimation only uses projects eligible for DBE subcontracting requirements.

Table 5: Parameter Estimates for the Log-Normal Cost Distribution

| | Coefficient | Standard Error |
|---|---|---|
| Constant | 0.776 | 0.200 |
| log(Engineer's Estimate) | 0.928 | 0.009 |
| log(Length + 1) | 0.031 | 0.009 |
| log(Planholders) | 0.018 | 0.078 |
| log(Subprojects) | 0.076 | 0.017 |
| Licenses | 0.030 | 0.014 |
| log(Working Days) | 0.021 | 0.011 |
| Federal Highway | 0.004 | 0.012 |
| Urban | -0.050 | 0.015 |
| District 2 | -0.044 | 0.017 |
| District 3 | -0.048 | 0.018 |
| District 4 | -0.005 | 0.020 |
| District 5 | -0.023 | 0.019 |
| District 6 | -0.049 | 0.018 |
| Bridge work | 0.020 | 0.022 |
| Lighting | -0.007 | 0.046 |
| Road Work | 0.060 | 0.026 |
| Safety Work | 0.022 | 0.024 |
| Stockpiling | 0.196 | 0.055 |
| $\sigma_c$ | 0.248 | 0.098 |

*Note:* Parameter estimates for the mean and standard deviation of log-costs.

The results for the cost distribution parameter estimates are presented in table 5. A non-DBE firm's cost is affected by a number of observable factors. In particular, the engineer's estimate is found to influence non-DBE firm costs; a one percent increase in the engineer's estimate corresponds to a 0.93 percent cost increase, and this coefficient is statistically significant. Although much of a non-DBE firm's cost is driven by the engineer's estimate, other observable project characteristics can influence the mean of the log-cost distribution. For example, a project's district ranges from decreasing non-DBE costs by 4.9 percent to 0.5 percent relative to a project that is located in district 1. The effect of the type of work requested on non-DBE costs ranges from decreasing the project cost by 0.7 percent to increasing non-DBE costs by 20.0 percent relative to projects classified as other.

Table 6: Parameter Estimates for the DBE Pricing and Fine Functions

| | Coefficient | Standard Error |
|---|---|---|
| $\sigma_u$ | | |
| Constant | 0.524 | 0.253 |
| DBE Req (%) | -0.185 | 0.057 |
| | | |
| Pricing Constant ($\alpha_0$) | 0.147 | 0.102 |
| $s_i$ ($\alpha_1$) | 0.527 | 0.289 |
| $\frac{s_i}{1-s_i}$ ($\alpha_2$) | 0.741 | 0.487 |
| 1/Subprojects ($\alpha_3$) | 0.107 | 0.051 |
| Fine Parameter ($\gamma$) | 2.649 | 8.076 |

*Note:* Parameter estimates for the DBE pricing and fine functions. The standard deviation of DBE pricing shocks is modeled as $\sigma_u = \exp(\sigma_{u1} + \sigma_{u2} DBE\,req)$, where $DBE\,req$ is the level of the DBE subcontracting reqirement.

The second set of estimated parameters include the parameters of the DBE pricing function and the fine function. These estimates are given in table 6. Higher DBE subcontracting requirements are associated with lower DBE pricing shocks, implying that the NMDOT is inclined to set these requirements when it is less costly to use DBE firms. The DBE pricing function parameters imply that, when the level of $u_w$ and the number of subprojects are fixed at their DBE-eligible means on a project with no DBE subcontracting requirement, choosing a DBE subcontracting share of 1 percent requires a payment of 1.9 percent of the project's estimated cost to DBE subcontractors. The parameter of the fine function, although noisy due to the small number of firms who do not comply with DBE requirements, implies that the fine associated with missing the DBE subcontracting requirement by 1 percent is 0.3 percent of the project's estimated cost. For the average engineer's estimate on projects with DBE subcontracting requirements, this fine amounts to $1,500. Although the literature currently has not established a benchmark for these parameters, the estimates and their interpretations appear to be reasonable.[30]

## 5.5 Model Fit

Model fit is first evaluated by comparing the predicted DBE shares and winning bids to the DBE shares and winning bids observed in the data on projects eligible for DBE subcontracting requirements. Figure 1 contains histograms comparing these two outcomes. In these histograms, the colored lines represent the

[30] Observe that the fine increases rapidly as the gap between the share and requirement increases. Missing the requirement by 2 percent amounts to a fine of $13,000, and missing the requirement by 5 percent results in a fine of $37,000.

density of the simulated outcomes, and the black lines represent the density of the actual outcomes. Winning bids are reported in logs for visual clarity.

The model fits the winning bids reasonably well but has difficulty replicating the distribution of DBE shares. DBE shares of zero are overpredicted by the model, and DBE shares between 0.05 and 0.10 are underpredicted. Given that this region of the DBE share distribution corresponds to the actual DBE subcontracting requirements, the model appears to have difficulty fitting the behavior of prime contractors who set their DBE shares as to just meet the subcontracting requirement.

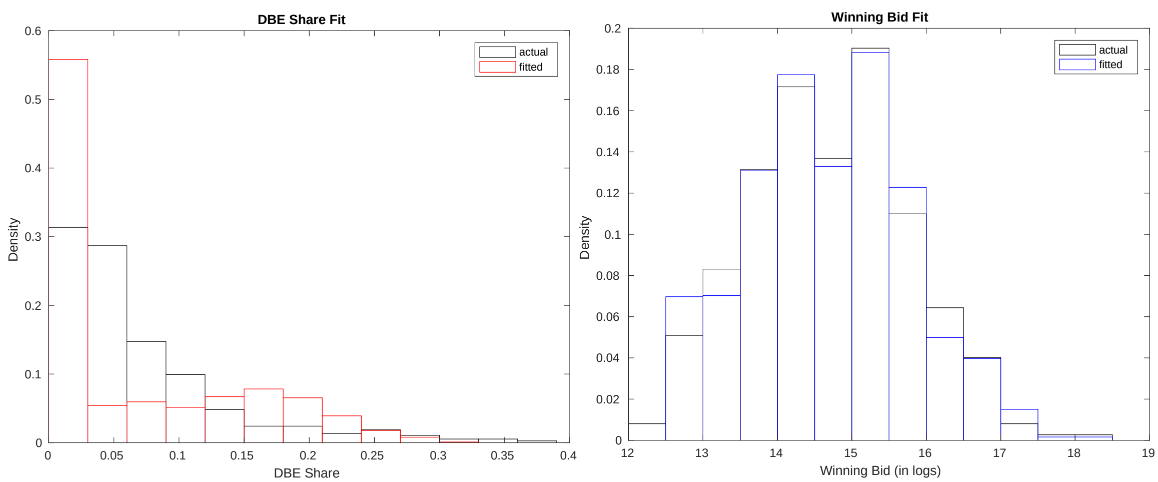



Figure 1: DBE Share and Winning Bid Outcome Fit

*Note:* This figure shows how the DBE shares and winning bids predicted from the empirical model compare to the DBE shares and winning bids observed in the data. The black lines correspond to the densities observed in the data, the red lines correspond to the predicted DBE share densities, and the blue lines correspond to the predicted winning bid densities.

To then compare how the model fits in the presence of DBE subcontracting requirements, the simulated and actual average DBE shares and winning bids are calculated for projects with and without DBE subcontracting requirements. The results are shown in table 7. The model moments match these data moments reasonably well. The model's average DBE subcontractor shares are within 0.45 percentage points of the true average DBE subcontractor shares, and the model's average winning bids are within $100,000 of the average winning bids in the data.

# 6 Counterfactual Analysis

The model parameter estimates are used to assess the relative costs of using DBE firms as well as predict counterfactual bidding and DBE subcontracting decisions under a variety of different policy alternatives.

Table 7: Model Fit

| | With Req. | | W/o Req. | |
|---|---|---|---|---|
| | Actual | Predicted | Actual | Predicted |
| DBE Share (%) | 9.15 | 8.70 | 4.30 | 4.23 |
| Winning Bid (in Millions) | 5.26 | 5.15 | 3.71 | 3.75 |

*Note:* This table compares the average winning bid and average DBE shares in the data to the ones predicted by the model.

First, a relative cost measure is created and used to explore the cost of using DBE firms relative to non-DBE firms. Three potential policy changes to New Mexico's current DBE program are then investigated: an increase in DBE subcontracting requirements, a decrease in DBE subcontracting requirements, and an elimination of DBE subcontracting requirements.

## 6.1 Relative Cost of DBE Firms

A criticism of requiring the use of DBE firms is that they are more costly to use as subcontractors. To assess whether this criticism is supported by the data, a measure of the cost of using DBE firms relative to non-DBE costs is generated for the two most common types of projects with subcontracting requirements: road projects and bridge projects. Given that these two projects can vary along other dimensions, the modal project characteristics for each type of project in the DBE-eligible data are used in constructing these measures.

The relative cost measure is constructed as the ratio of the cost for DBE firms to complete $s_i$ percent of a project $(P(s_i))$ to the cost of prime contractors to complete $s_i$ percent of a project by themselves or with non-DBE subcontractors $(c_i s_i)$. When the ratio is one, it is just as costly for a prime contractor to use DBE firms as their own resources, and when the ratio is greater than one, DBE firms are relatively more expensive. Given that the price of DBE firms also depends on the realization of the DBE pricing shock, this ratio is plotted for the $25^{th}$, $50^{th}$ and $75^{th}$ percentiles of the shock's distribution.

Figure 2 illustrates how the relative cost of using DBE firms changes across different projects and price shock realizations. For both types of projects, DBE firms are likely to be relatively more costly since the cost ratio is greater than one for most draws of the pricing shock. There are regions of the cost shock distribution where DBE firms are much less costly, which indicates that DBE utilization is sensitive to the realization of the shock.

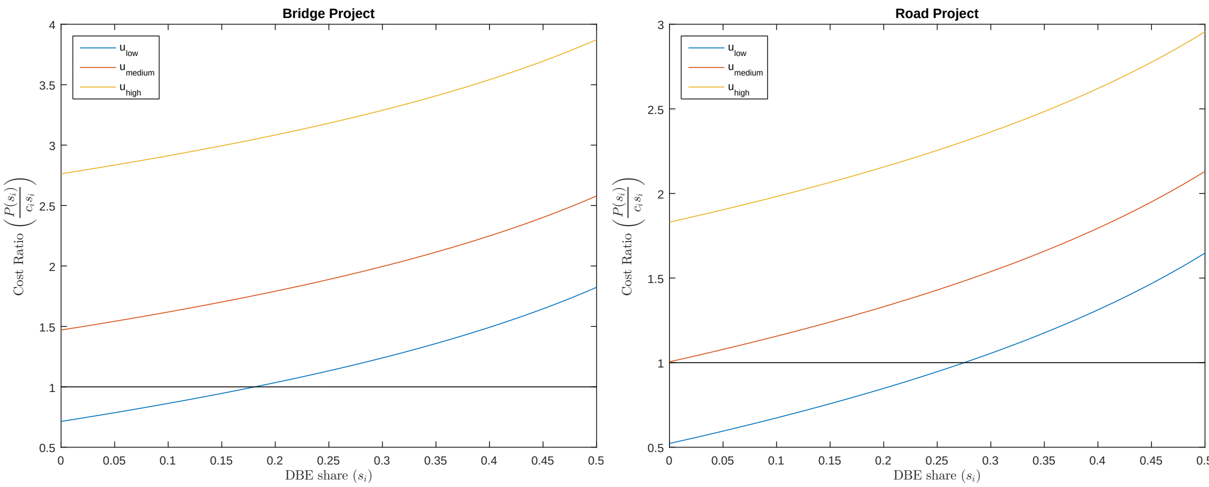



Figure 2: Relative Costs of Using DBE Firms

*Note:* This figure shows the cost of using DBE firms relative to non-DBE costs for the modal bridge and road construction projects. The vertical axis has the cost ratio, and the horizontal axis has the DBE share. The different lines correspond to different levels of the unobserved shock on the DBE pricing function, where "low" corresponds to the $25^{th}$ percentile, "medium" corresponds to the $50^{th}$ percentile, and high corresponds to the $75^{th}$ percentile of the shock's distribution.

## 6.2 Alternative DBE Requirements

To investigate how DBE subcontracting requirements affect procurement, auction outcomes under a variety of different subcontracting requirement levels are simulated from the model. This analysis, with the exception of elimination, focuses on percent changes to the existing DBE subcontracting requirements to be consistent with the types of projects on which the NMDOT establishes these requirements. This type of policy adjustment is akin to a uniform change in all DBE subcontracting requirements, with more change given to projects with higher observed subcontracting requirements. The reported policy experiments include data from the model simulated under a 50 percent increase in the DBE subcontracting requirement, no change in the DBE subcontracting requirement, and a 50 percent decrease in the DBE subcontracting requirement.

The averages of six auction outcomes are reported for each policy experiment on projects with subcontracting requirements. *DBE share* is the simulated share of work going to DBE firms, while *Winning bid* refers to the simulated winning bid. *Effective cost* corresponds to $\phi$, which is the total cost of completing a project that includes using DBE subcontractors. *Rent reduction* is the dollar value of the reduction in rents associated with using DBE subcontractors. Theoretically, this outcome coincides with the expression $s\left(c_i\right)\frac{\int_{c_i}^{\overline{c}}\left(1-F(\tilde{c})\right)^{N-1}d\tilde{c}}{\left(1-F(c_i)\right)^{N-1}}$ and can be interpreted as the fraction of a non-DBE firm's rent lost by using DBE subcontractors instead of their own resources. *DBE payments* is the portion of the winning bid used to pay

DBE firms, and *firm profits* is the amount of money the winning non-DBE firms gain from completing the project.

Table 8: Counterfactual Goal Levels

| | increase | baseline | decrease | elimination |
|---|---|---|---|---|
| DBE share (%) | 9.02 | 8.70 | 8.49 | 8.40 |
| Winning Bid (in 1000s) | 5159.92 | 5149.72 | 5143.58 | 5141.47 |
| Effective Cost (in 1000s) | 4711.83 | 4699.84 | 4692.46 | 4689.89 |
| Rent Reduction (in 1000s) | 33.27 | 31.47 | 30.23 | 29.77 |
| DBE Payments (in 1000s) | 335.65 | 314.61 | 300.54 | 296.12 |
| Firm Profits (in 1000s) | 448.09 | 449.89 | 451.12 | 451.58 |

*Note:* This table shows the average auction outcomes for different requirement levels on auctions with DBE subcontracting reqirements. Effective costs are the costs to non-DBE firms while accounting for DBE subcontracting. Rent reduction is the dollar value of information rents non-DBE firms lose as a result of using DBE subcontractors. DBE payments are the average payments to DBE firms, and firm profits are the non-DBE profits of the winning contractor.

The results from the policy experiments are shown in table 8. As a general trend, increasing the subcontracting requirements decreases profits to non-DBE firms, while the remaining outcomes increase. Intuitively, the increase in the requirements gives firms an incentive to use more DBE subcontractors. More DBE subcontractors result in higher payments to DBE firms which, in turn, leads to higher effective costs and lower non-DBE firm profits. Although the rent reduction counteracts the increase in effective costs, the rent reduction is not high enough to lower the average winning bid, so the average winning bid increases. These effects are modest, though, since the fine function only affects the decisions of firms that would otherwise subcontract below the DBE subcontracting requirement.

To evaluate New Mexico's current policy, the baseline model's predictions are compared to the predictions of the model when there are no DBE subcontracting requirements. These simulations predict that New Mexico's current requirements have a small effect on the realized DBE shares and procurement costs. Eliminating New Mexico's DBE subcontracting requirements would result in a 0.3 percentage point (or 3.4 percent) decrease in the average share of work allocated to DBE subcontractors on projects with subcontracting requirements. This decrease corresponds to a $\$8,250$ (or 0.2 percent) decrease in the average cost of procurement and a $\$1,690$ (or 0.4 percent) increase in non-DBE firm profits. The small effect of DBE subcontracting requirements on auction outcomes is generated through the high fraction of firms who presently exceed the DBE subcontracting requirement. Firms that already subcontract above and beyond these requirements, as many firms do in the data, do not change their subcontracting behavior in response to a lower requirement. As a result, the auction outcomes do not change much in the presence of DBE subcontracting requirements.

# 7 Conclusion

This paper theoretically and empirically examines how subcontracting requirements affect government procurement auctions. The required subcontracting component can cause firms to use similar preferred subcontractors, leading to a common component in costs. Theoretically, this common cost component reduces information rents and can work to lower the costs of using potentially less cost-effective firms.

The policy experiments considered in this paper illustrate the impact of subcontracting requirements on procurement. Altering the existing DBE subcontracting requirements has modest effects on DBE participation and procurement costs, since many of the firms in the data already subcontract above and beyond the required percentages. Eliminating the DBE subcontracting requirement would result in a 3.4 percent reduction in the share of construction projects awarded to DBE firms, a 0.2 percent reduction in the average procurement costs, and a 0.4 percent increase in non-DBE firm profits relative to the NMDOT's current DBE subcontracting requirements. These results suggest that New Mexico's current policy is not responsible for large increases in procurement costs.

Although this paper focuses on subcontracting requirements, there are a variety of different policies governments can use to increase the participation of preferred bidders. For example, two popular policies for fostering the participation of preferred firms are bid discounts and set-aside auctions. A possible direction for future research would then be to compare these different programs with subcontracting requirements in how effective they are at improving preferred participation.

# References


Susan Athey. Single crossing properties and the existence of pure strategy equilibria in games of incomplete information. *Econometrica*, 64(4):861 – 889, July 2001.

Susan Athey, Dominic Coey, and Jonathan Levin. Set-asides and subsidies in auctions. *American Economic Journal: Microeconomics*, 5(1):1–27, 2013.

Nicola Branzoli and Francesco Decarolis. Entry and subcontracting in public procurement auctions. *Management Science*, 61(12):2945–2962, 2015.

Dakshina G. De Silva, Timothy Dunne, Georgia Kosmopoulou, and Carlos Lamarche. Disadvantaged business enterprise goals in government procurement contracting: An analysis of bidding behavior and costs. *International Journal of Industrial Organization*, 30:377–388, 2012.

Dakshina G. De Silva, Timothy P. Hubbard, and Georgia Kosmopoulou. Efficacy of a bidder training program: Lessons from linc. Working Paper, October 2015.

Dakshina G. De Silva, Georgia Kosmopoulou, and Carlos Lamarche. Subcontracting and the survival of plants in the road construction industry: A panel quantile regression analysis. Working Paper, April 2016.

Christian Gourieroux, Alain Monfort, and Eric Renault. Indirect inference. *Journal of Applied Econometrics*, 8:S85 – S118, December 1993.

Emmanuel Guerre, Isabelle Perrigne, and Quang Vuong. Optimal nonparametric estimation of first-price auctions. *Econometrica*, 68(3):525–574, May 2000.

Timothy P. Hubbard and Harry J. Paarsch. Investigating bid preferences at low-price, sealed-bid auctions with endogenous participation. *International Journal of Industrial Organization*, 27:1–14, 2009.

Przemyslaw Jeziorski and Elena Krasnokutskaya. Dynamic auction environment with subcontracting. The RAND Journal of Economics (forthcoming), September 2014.

Mireia Jofre-Bonet and Martin Pesendorfer. Estimation of a dynamic auction game. *Econometrica*, 71(5): 1443 – 1489, September 2003.

Elena Krasnokutskaya and Katja Seim. Bid preference programs and participation in highway procurement auctions. *American Economic Review*, 101:2653–2686, October 2011.

Bernard Lebrun. Uniqueness of the equilibrium in first-price auctions. *Games and Economic Behavior*, 55: 131–151, 2006.

Tong Li and Xiaoyong Zheng. Entry and competition effects in first-price auctions: Theory and evidence from procurement auctions. *Review of Economic Studies*, 76(4):1397–1429, 2009.

Justin Marion. Are bid preferences benign? the effect of small business subsidies in highway procurement auctions. *Journal of Public Economics*, 91:1591–1624, January 2007.

Justin Marion. How costly is affirmative action? government contracting and california's proposition 209. *The Review of Economics and Statistics*, 91(3):503–522, August 2009.

Justin Marion. Affirmative action and the utilization of minority- and women-owned business in highway procurement. *Economic Inquiry*, 49(3):899–915, July 2011.

Justin Marion. Sourcing from the enemy: Horizontal subcontracting in highway procurement. *The Journal of Industrial Economics*, 63(1):100 – 128, March 2015a.

Justin Marion. Affirmative action and capacity constrained firms: Evidence from good faith effort exemptions in public procurement. Working Paper, October 2015b.

Paul Milgrom and Ilya Segal. Envelope theorems for arbitrary choice sets. *Econometrica*, 70(2):583 – 601, March 2002.

Daniel P. Miller. Subcontracting and competitive bidding on incomplete procurement contracts. *The RAND Journal of Economics*, 45(4):705 – 746, 2014.

Luigi Moretti and Paola Valbonesi. Subcontracting in public procurement: An empirical investigation. Working Paper, March 2012.

Jun Nakabayashi. Small business set-asides in procurement auctions: an empirical analysis. *Journal of Public Economics*, 100:28–44, 2013.

Jun Nakabayashi and Naoki Watanabe. An experimental study of bidding behavior in subcontract auctions. Tsukuba Economics Working Papers No. 2010-009, December 2010.

*Consultant Services Procedures Manual*. New Mexico Department of Transportation, July 2014. http://dot.state.nm.us/en/Program_Management.html.

*Disadvantaged Business Enterprise Program Manual*. New Mexico Department of Transportation Office of Equal Opportunity Programs, February 2012. http://dot.state.nm.us/en/OEOP.html#c.

OECD. Government at a glance 2015. OECD publishing, Paris, 2015. doi: http://dx.doi.org/10.1787/gov_glance-2015-en.

Philip J. Reny and Shmuel Zamir. On the existence of pure strategy monotone equilibria in asymmetric first-price auctions. *Econometrica*, 72(4):1105–1125, July 2004.

Benjamin Rosa. Resident bid preference, affiliation, and procurement competition: Evidence from new mexico. MPRA Working Paper, July 2016.

Anthony A. Smith. Estimating nonlinear time-series models using simulated vector autoregressions. *Journal of Applied Econometrics*, 8:S63 – S84, 1993.

# A Proofs

## A.1 Properties of the Optimal DBE Subcontracting Decision

### A.1.1 Second-Order Conditions

The sufficient condition on optimal DBE subcontracting for each task is given by the following expression:

$$-P_t''(s_{i,t}) - \frac{\varphi_{s_t s_t}(\boldsymbol{s}_i;\overline{s})}{\tau_t} < 0.$$

Observe that this condition will be satisfied for a $\varphi$ that is convex in all of its arguments and an increasing and convex $P_t$.

### A.1.2 Comparative Statics

The concern here is in understanding how the optimal DBE subcontracting share changes with $c_i$. Differentiating equation 2 while taking into account the optimal DBE subcontracting strategy yields

$$1 = P_t''(s_t(c_i;\overline{s}))\, s_t'(c_i;\overline{s}) + \frac{\varphi_{s_t s_t}(\boldsymbol{s}(c_i;\overline{s});\overline{s})\, s_t'(c_i;\overline{s})}{\tau_t}.$$

After some algebraic manipulation, the above equation reduces to

$$s_t'(c_i;\overline{s}) = \frac{\tau_t}{\tau_t P_t''(s_t(c_i;\overline{s})) + \varphi_{s_t s_t}(\boldsymbol{s}(c_i;\overline{s});\overline{s})},$$

which is increasing given the sufficient conditions.

## A.2 Derivation of the Bidding Function (Proposition 1)

The bidding function is derived from an envelope theorem argument. In particular, the utility a bidder gains from a cost realization $c_i$ is

$$U(c_i;\overline{s}) = \left(b(c_i;\overline{s}) - \sum_{t=1}^{T} \tau_t \left(c_i\left(1 - s_t(c_i;\overline{s})\right) - P_t\left(s_t(c_i;\overline{s})\right)\right) - \varphi\left(\boldsymbol{s}(c_i;\overline{s});\overline{s}\right)\right)\left(1 - F(c_i)\right)^{N-1}. \qquad (11)$$

Alternatively, if bidder $i$ is playing a best response, it must be the case that

$$U(c_i;\overline{s}) = \max_{\{b_i,\boldsymbol{s}_i\}} \left(b_i - \sum_{t=1}^{T} \tau_t\left(c_i\left(1 - s_{i,t}\right) - P_t(s_{i,t})\right) - \varphi(\boldsymbol{s}_i;\overline{s})\right)\left(1 - F\left(b^{-1}(b_i)\right)\right)^{N-1}.$$

Apply the envelope theorem to get[31]

$$\frac{d}{dc}U\left(c;\overline{s}\right)\bigg|_{c=c_i}=\sum_{t=1}^{T}\tau_t\left(s_{i,t}-1\right)\left(1-F\left(c_i\right)\right)^{N-1}.$$

Integrate the above expression to get another expression for $U\left(c_i;\overline{s}\right)$:

$$U\left(c_i;\overline{s}\right)=U\left(\overline{c};\overline{s}\right)+\sum_{t=1}^{T}\tau_t\left(1-s_{i,t}\right)\int_{c}^{\overline{c}}\left(1-F\left(\tilde{c}\right)\right)^{N-1}d\tilde{c}. \tag{12}$$

Given that bids are assumed to be increasing in effective costs, it must be the case that any bidder who draws a cost of $\overline{c}$ cannot win with positive probability in equilibrium. Therefore, set $U\left(\overline{c};\overline{s}\right)=0$ and equate the right hand side of equations 11 and 12 to get the optimal bidding function in equation 6.

It is important to understand the shape of the bidding function since there is a region where two different draws of $c_i$ could potentially lead to the same bid. Specifically, the optimal bid function will be flat in $c_i$ whenever $s_t\left(c_i;\overline{s}\right)=1$ for all $t$ and increasing in $c_i$ whenever $s_t\left(c_i;\overline{s}\right)\in[0,1)$ for at least one $t$. This result is intuitive since firms who subcontract the entire project to DBE firms will have the same effective cost independent of their non-DBE cost. In the data, no firms subcontract the entire project to DBE firms, so the empirical application avoids this potential theoretical problem.

## A.3 Proof of Increasing DBE Subcontractor Shares (Proposition 2)

**Proposition.** *For a given task $t$, if $s_t\left(c_i;0\right)\neq s_t\left(c_i;\overline{s}\right)$, then $s_t\left(c_i;0\right)<s_t\left(c_i;\overline{s}\right)$.*

*Proof.* By the first order conditions on optimal DBE subcontracting,

$$c_i=P_t'\left(s_{i,t}\right)+\frac{\varphi_{s_t}\left(\boldsymbol{s}_i;\overline{s}\right)}{\tau_t}.$$

Given the assumption $s_t\left(c_i;0\right)\neq s_t\left(c_i;\overline{s}\right)$, it must be the case that $\frac{\varphi_{s_t}\left(\boldsymbol{s}_i;\overline{s}\right)}{\tau_t}<0$. When that inequality holds, prime contractors find it optimal to increase their DBE shares $s_{i,t}$ when there is a DBE subcontracting requirement. There are now three possible cases for $s_t\left(c_i;0\right)$ and $s_t\left(c_i;\overline{s}\right)$[32]: both solutions are interior solutions, one of the two solutions is an interior solution while the other is a corner solution, or both solutions

[31] To invert the bid function in this step, it is implicitly assumed that bids are increasing in $c_i$ rather than effective costs. Indeed, bids will be increasing in $c_i$ so long as $s_t\left(c_i;\overline{s}\right)<1$ for at least one $t$ using the results from equation 5, but this assumption on costs could be problematic if $s_t\left(c_i;\overline{s}\right)=1$ for all $t$ since effective costs are flat in $c_i$. As a result, the following analysis only holds for $s_t\left(c_i;\overline{s}\right)\in[0,1)$ for at least one $t$, but the derived expression for the bid function in terms of $c_i$ will also hold when $s_t\left(c_i;\overline{s}\right)=1$ for all $t$.

[32] Since prime contractors find it optimal to increase the share when there is a requirement, any case where $s_t\left(c_i;0\right)>s_t\left(c_i;\overline{s}\right)$ is not possible. The assumption that $s_t\left(c_i;0\right)\neq s_t\left(c_i;\overline{s}\right)$ rules out the cases where both solutions occur at the same corner.

occur at different corners. In either of these three cases $s_t(c_i;0) < s_t(c_i;\overline{s})$. □

### A.4 Proof of Bid Ambiguity (Corollary 1)

**Corollary.** *If $s_t(c_i;0) < s_t(c_i;\overline{s})$ for at least one task, then DBE subcontracting requirements have an ambiguous effect on equilibrium bids.*

*Proof.* Given that $P_t$ is increasing and $s_t(c_i;0) < s_t(c_i;\overline{s})$ for at least one task, the following four inequalities must hold.

1. $\sum_{t=1}^{T} \tau_t (1 - s_t(c_i;0)) \frac{\int_{c_i}^{\overline{c}} (1-F(\tilde{c}))^{N-1} d\tilde{c}}{(1-F(c_i))^{N-1}} > \sum_{t=1}^{T} \tau_t (1 - s_t(c_i;\overline{s})) \frac{\int_{c_i}^{\overline{c}} (1-F(\tilde{c}))^{N-1} d\tilde{c}}{(1-F(c_i))^{N-1}}$.
2. $\sum_{t=1}^{T} \tau_t P_t(s_t(c_i;0)) < \sum_{t=1}^{T} \tau_t P_t(s_t(c_i;\overline{s}))$.
3. $\sum_{t=1}^{T} \tau_t c_i (1 - s_t(c_i;0)) > \sum_{t=1}^{T} \tau_t c_i (1 - s_t(c_i;\overline{s}))$.
4. $\varphi(\boldsymbol{s}(c_i;0);0) > \varphi(\boldsymbol{s}(c_i;\overline{s});\overline{s})$.

The fourth inequality comes from the result that $\varphi$ must be decreasing in the task where $s_t(c_i;0) < s_t(c_i;\overline{s})$. Given the direction of these inequalities, the total effect of subcontracting requirements on bids is ambiguous. □

It is worth noting that if the DBE share increases for multiple tasks, then the bid ambiguity proof still applies since the inequalities still hold in the same direction.

## B Microfoundations for the DBE Pricing Function

The theoretical model takes the DBE pricing function on task $t$ as given in its formulation of the optimal bidding and DBE subcontracting strategies. Theoretically, the DBE pricing function can arise from a variety of different market structures, each unique to the required task. This section explores two different types of market structures and derives their respective DBE pricing functions. Throughout this section, a DBE firm performing work in task $t$ will have a thrice continuously differentiable cost function given by $C_t : [0,1] \to \mathbb{R}$ that maps the requested share of work into a cost for the firm. Furthermore, it is assumed that $C_t', C_t'', C_t''' > 0$ so that the cost function will result in an increasing and convex pricing function consistent with the pricing function presented in the paper.

### Perfect Competition

Some tasks may have DBE firms who behave competitively as price takers. For these tasks, DBE firms solve the following profit maximization problem:

$$\max_{s\geq 0} P_t s - C_t\left(s\right).$$

The first-order conditions generate the following relationship between prices and costs:

$$P_t\left(s\right) = C_t'\left(s\right).$$

In other words, the pricing function reflects the marginal cost of the DBE firms.

### Monopoly

In contrast to the competitive case, there may be some tasks where there is only one DBE firm in the market. This DBE firm will then behave as a monopolist, solving the following profit maximization problem:

$$\max_{s\geq 0} P_t\left(s\right) s - C_t\left(s\right).$$

The monopolist's pricing decision that arises from its first order conditions can be written as

$$P_t\left(s\right) = \frac{1}{1+\frac{1}{\epsilon}} C_t'\left(s\right),$$

where $\epsilon = \frac{ds/s}{dP/P}$ is the price elasticity of demand. In words, the pricing function represents the monopolist's markup over its marginal cost.[33]

# C Estimation Appendix

The parameters of the model are estimated using indirect inference, which essentially estimates the mapping between the structural parameters of the model and the reduced form parameters of the auxiliary model. In order to maintain desirable properties of the model across different parameter guesses, restrictions must be

[33]Note that it is implicitly assumed that the monopolist firm does not strategically take the fine function into consideration when determining its prices.

placed on the model's parameters. These restrictions along with details on the auxiliary model selection are included in this appendix.

## C.1 Parametric Restrictions

The parameters are restricted such that the pricing function is convex and increasing in the DBE share and the fine function is convex and non-increasing in the share. To illustrate these restrictions, consider the first and second order conditions of the DBE pricing function and the fine function for any given auction:

$$\begin{aligned} P'(s_i) &= \left(\alpha_0 + \alpha_1 s_i + \alpha_2 \frac{s_i}{1-s_i} + \alpha_3' \boldsymbol{z}_w + u_w\right)\hat{x} + \left(\alpha_1 + \frac{\alpha_2}{(1-s_i)^2}\right) s_i \hat{x} \\ \varphi'(s_i;\bar{s}) &= \begin{cases} 2\gamma(s_i - \bar{s})\hat{x} & \text{if } s_i < \bar{s} \\ 0 & \text{if } s_i \geq \bar{s} \end{cases} \end{aligned}$$

$$\begin{aligned} P''(s_i) &= 2\left(\alpha_1 + \frac{\alpha_2}{(1-s_i)^2}\right)\hat{x} + \left(\frac{2\alpha_2}{(1-s_i)^3}\right) s_i \hat{x} \\ \varphi''(s_i;\bar{s}) &= \begin{cases} 2\gamma\hat{x} & \text{if } s_i < \bar{s} \\ 0 & \text{if } s_i \geq \bar{s} \end{cases}. \end{aligned}$$

Observe that restricting $\alpha_0 > 0$, $\alpha_1 > 0$, $\alpha_2 > 0$ and $\alpha_3 > 0$ will generate a DBE pricing function that is convex and increasing in the DBE share for $s_i \in [0, 1)$. Similarly, restricting $\gamma > 0$ will produce a fine function that is convex and non-increasing for $s_i \in [0, 1]$. These properties encourage the DBE pricing function and fine function to behave properly during estimation.

## C.2 Auxiliary Models and Criterion Function

The auxiliary model for the winning bid is an OLS regression of the log-winning bid on all auction-level observables, and the auxiliary model for the DBE shares is an OLS regression of the DBE shares on all auction-level observables. In particular, if $s_w$ is the share of the project the winning bidder allocates to DBE firms in auction $w$ and $b_w$ is the winning bidder's bid in auction $w$, then the DBE share and winning bid are modeled as

$$
\begin{aligned}
s_w &= \begin{bmatrix} \boldsymbol{x}_w \\ \bar{s}_w \end{bmatrix}' \beta_s + \epsilon_{sw} \\
\log(b_w) &= \begin{bmatrix} \boldsymbol{x}_w \\ \bar{s}_w \end{bmatrix}' \beta_b + \epsilon_{bw},
\end{aligned}
$$

where $\beta_s$ are the parameters of the DBE share auxiliary model, $\beta_b$ are the parameters of the winning bid auxiliary model, $\epsilon_{sw}$ is the error term on the DBE share auxiliary model, and $\epsilon_{bw}$ is the error term on the winning bid auxiliary model. The standard OLS assumptions on the error term are assumed to hold in this formulation.

The criterion function is formed using methods described in section 4.3. Let $\beta_w = [\beta_s, \beta_b]'$ be the stacked parameters of the auxiliary models. Then the structural parameters, $\theta$, are chosen to minimize the distance between the auxiliary parameters from the data, and the auxiliary parameters generated from $H$ simulations of the $W$ total auctions:

$$
\hat{\theta} \in \arg\min_{\theta \in \Theta} \left[\hat{\beta}_W - \tilde{\beta}_{HW}(\theta)\right]' \hat{\Omega}_W \left[\hat{\beta}_W - \tilde{\beta}_{HW}(\theta)\right],
$$

where $\hat{\beta}_W$ are the estimated auxiliary parameters from the data, $\tilde{\beta}_{HW}$ are the estimated auxiliary parameters from the simulations, and $\hat{\Omega}_W$ is some positive definite weighting matrix that is set to the optimal weighting matrix during estimation.

## C.3 Standard Errors and Optimal Weighting Matrix

Following Gourieroux et al. (1993), the asymptotic distribution of the indirect inference estimator takes the following form:

$$
\sqrt{W}\left(\hat{\theta}_{HW} - \theta_0\right) \xrightarrow{d} \mathcal{N}\left(0, V_\theta\right)
$$

with

$$
V_\theta = \left(1 + \frac{1}{H}\right) \left(D'\Omega D\right)^{-1} D'\Omega V_{\beta_0} \Omega D \left(D'\Omega D\right)^{-1},
$$

$$
D = \frac{\partial \beta_0}{\partial \theta_0'},
$$

and

$$\sqrt{W}\left(\tilde{\beta}_{HW}-\beta_0\right)\xrightarrow{d}\mathcal{N}\left(0,V_{\beta_0}\right).$$

Notation wise, $\hat{\theta}_{HW}$ are the structural parameters estimated from the data, $\theta_0$ are the true structural parameters, $\Omega$ is a positive definite weighting matrix, $\beta_0$ are the auxiliary parameters evaluated using the true structural parameters, and $\xrightarrow{d}$ denotes convergence in distribution. The optimal weight matrix in this setting is $\Omega^{\star}=\left(V_{\beta_0}\right)^{-1}$, yielding an asymptotic variance of $V_{\theta}=\left(1+\frac{1}{H}\right)\left(D'\Omega^{\star}D\right)^{-1}$.

In practice, the objects of the asymptotic distribution are replaced by consistent estimators. Specifically, the following consistent estimators are used in place of their asymptotic counterparts:

$$\hat{D}=\frac{\partial\beta_{HW}\left(\hat{\theta}_{HW}\right)}{\partial\hat{\theta}'_{HW}}$$

and

$$\hat{\Omega}^{\star}=\left(\hat{V}_{\beta_{HW}\left(\hat{\theta}_{HW}\right)}\right)^{-1}.$$

In constructing $\hat{V}_{\beta_{HW}\left(\hat{\theta}_{HW}\right)}$, the estimator for $V_{\beta_0}$, a parametric bootstrap procedure is used on the data.

# D Estimated Pricing and Fine Functions

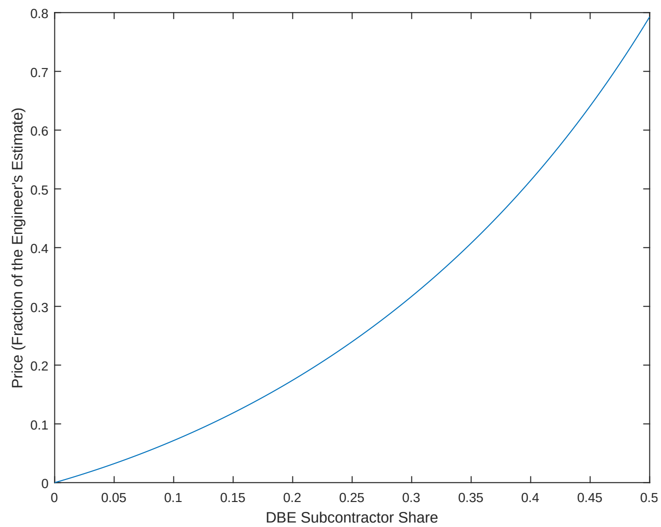



Figure 3: The DBE Pricing Function as a Fraction of the Engineer's Estimate

*Note:* This figure shows a plot of the price of using DBE subcontractors as a fraction of the engineer's estimate, which corresponds to the expression $\frac{P(s_i)}{\hat{x}}$. Here, the pricing function is evaluated using the mean level of subprojects in the DBE-eligible data and the mean level of the unobservable pricing shock term ($\sigma_u$) when there is an established DBE subcontracting requirement of 7.5 percent.

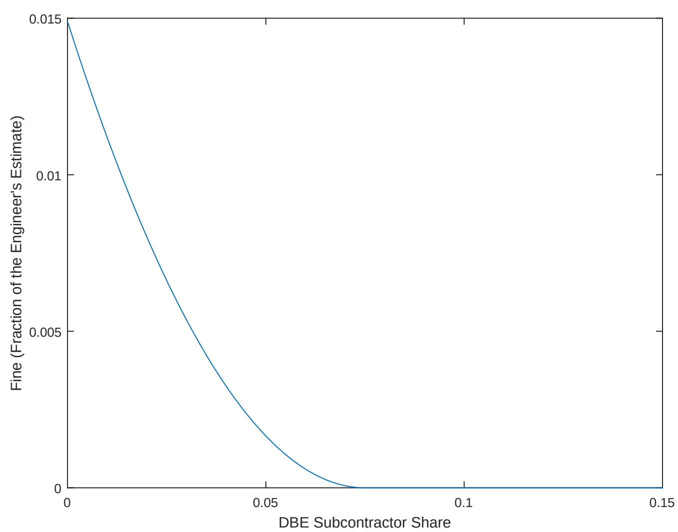



Figure 4: Fine Function as a Fraction of the Engineer's Estimate

*Note:* This figure shows the estimated fine function as a fraction of the engineer's estimate, corresponding to the expression $\frac{\varphi(s_i;\bar{s})}{\hat{x}}$. The fine function is evaluated when there is an established DBE subcontracting requirement of 7.5 percent.

# E Invitation for Bids

The majority of the observable variables are gathered from the invitation for bids document that the NMDOT publishes to advertise its available construction projects. Figure 5 contains an excerpt from the NMDOT's January 22nd, 2010 advertisement. The county, which is later aggregated up to administrative district, and length are given in the first paragraph. The second paragraph lists project components. Here, the component in uppercase letters (in this case, roadway rehabilitation) is taken to be the main project, and the following components are taken to be subprojects. The third paragraph gives the working days, and the fourth paragraph states whether there is a DBE subcontracting requirement (or goal). The last paragraph gives the licensing requirements.

(7)
FEDERAL AID PROJECT
ES21420
CN ES21420

NM 209, MP 7.67 to MP 12.51 located in Curry County. The approximate length is 4.848 miles.

Construction Consists Of:
ROADWAY REHABILITATION, (Processing, Placing & Compacting Existing Pavement w/Overlay (Flexible)), Roadway Reconstruction (Flexible), Earthwork (Borrow, Subexcavation), Metal Barrier Installation, Traffic Control (Phasing) and Miscellaneous Construction.

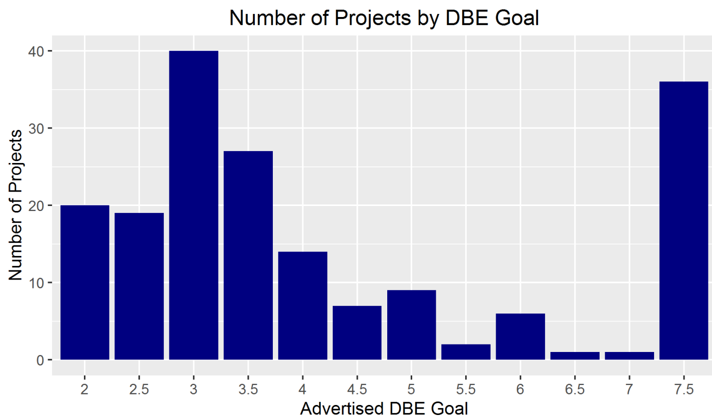
This contract must be completed in 60 working days.

At this time NMDOT will meet the State DBE Goal on Federally assisted projects through a combination of race-neutral and race-conscious measures. This project is subject to race-conscious measures. The established DBE goal for this project is 3.5%.

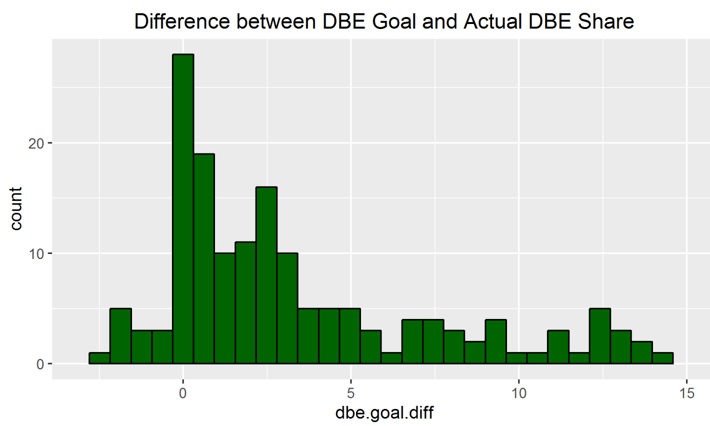
The Contractor may bid and contract as the prime contractor of the entire project, provided he holds the proper classification for the major portion of the work to be performed based on dollar amount. The following New Mexico License classification(s) are required to perform the work called for on this project: (GA-1 or GA-98).

Figure 5: IFB Example

# F Additional Regressions and Graphs




*Note:* This figure shows the distribution of non-zero DBE subcontracting requirements.




*Note:* This figure shows the percentage difference between the share of DBE subcontractors actually used on a given project and the DBE subcontracting requirement conditional on the project having a subcontracting requirement. Although there is some bunching at 0 percent, there is a non-trivial mass of projects where contractors exceed the subcontracting requirement by more than 1 percent. Consequently, a continuous function is used to approximate the change in incentives induced by having a DBE subcontracting requirement rather than a discrete function. This figure is truncated at 15 percent for visual clarity.

Tables 9 and 10 motivate the main modeling assumptions of the paper. Table 9 contains a regression specification very similar to the first three columns of tables 2 and 3, but a control for firm capacity (as measured by the project backlog of a firm divided by the maximum backlog of the firm during the sample period) is included as an additional observable. This regression motivates the absence of capacity constraints in the paper's main analysis; the statistically insignificant coefficient on the capacity measure shows that there is insufficient descriptive evidence in favor of including firm capacity in firm bidding and DBE subcontracting decisions. Similarly, table 10 is a regression that explores firm entry decisions as measured by the number of planholders and the fraction of bidders over the number of planholders. Although entry is typically modeled as an endogenous decision in these types of procurement models, the lack of an economically and statistically significant coefficient on the DBE requirement variable suggests that entry is not a first-order concern in evaluating these DBE participation policies.

Table 9:

| | *Dependent variable:* | |
|---|---|---|
| | log(Winning Bid) | DBE Share (%) |
| | (1) | (2) |
| log(engineer) | $0.927^{***}$ | $-0.352$ |
| | (0.017) | (0.624) |
| dbe | 0.002 | $1.014^{***}$ |
| | (0.004) | (0.184) |
| log(length + 1) | $0.043^{***}$ | 0.016 |
| | (0.014) | (0.511) |
| capacity | $-0.019$ | $-0.355$ |
| | (0.040) | (1.161) |
| log(planholders) | 0.007 | 1.610 |
| | (0.056) | (1.940) |
| log(subprojects) | $0.049^{*}$ | 1.432 |
| | (0.028) | (0.880) |
| license_count | $0.044^{**}$ | $1.773^{*}$ |
| | (0.020) | (0.924) |
| log(working_days) | $0.038^{*}$ | $-0.613$ |
| | (0.020) | (0.605) |
| bidders | $-0.018^{***}$ | $-0.058$ |
| | (0.005) | (0.215) |
| as.factor(federal_highway)1 | $-0.034$ | $-0.240$ |
| | (0.022) | (0.690) |
| as.factor(urban)1 | $-0.018$ | $1.899^{*}$ |
| | (0.034) | (0.970) |
| Observations | 389 | 389 |
| Adjusted $R^2$ | 0.985 | 0.227 |

*Note:* $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01
Regression includes controls for district and type of work as well as month and year fixed effects. Standard errors are robust.

Table 10:

| | *Dependent variable:* | |
|---|---|---|
| | Bidders/Planholders | Planholders |
| | (1) | (2) |
| log(engineer) | 0.008 | 1.392*** |
| | (0.008) | (0.353) |
| dbe | 0.0005 | 0.105 |
| | (0.002) | (0.087) |
| log(length + 1) | 0.010 | −1.239*** |
| | (0.006) | (0.314) |
| log(subprojects) | −0.001 | 3.417*** |
| | (0.016) | (0.589) |
| license_count | −0.022** | 1.194*** |
| | (0.009) | (0.457) |
| log(working_days) | −0.018* | 1.554*** |
| | (0.011) | (0.408) |
| as.factor(federal_highway)1 | 0.001 | −0.543 |
| | (0.011) | (0.429) |
| as.factor(urban)1 | 0.002 | 1.522** |
| | (0.016) | (0.619) |
| Observations | 389 | 389 |
| Adjusted $R^2$ | 0.115 | 0.708 |

*Note:* *p<0.1; **p<0.05; ***p<0.01

Regression includes controls for district and type of work as well as month and year fixed effects. Standard errors are robust.