Subcontracting Requirements and the Cost of Government Procurement

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Abstract

Government procurement contracts are frequently subject to policies that specify, as a percentage of the total project, a subcontracting requirement for the utilization of historically disadvantaged firms. I study how such subcontracting policies affect procurement auction outcomes using administrative data from New Mexico's Disadvantaged Business Enterprise (DBE) Program. My analysis is based on a procurement auction model with endogenous subcontracting. Theoretically, I show that subcontracting requirements need not translate into substantially higher procurement costs – even when disadvantaged firms are relatively more costly. The intuition behind this result is that subcontracting programs require that prime contractors select their subcontractors from a common pool of disadvantaged firms, which reduces the private information prime contractors have on their own project-completion costs. As a result of losing private information, prime contractors strategically reduce their markups in their bids, and the reduction in markups can be sufficiently high to mitigate the cost increases from using more costly subcontractors. I estimate an empirical version of the model and find that New Mexico's past subcontracting requirements led to only small increases in procurement costs.

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] The government awards a portion of that spending to firms that, because of either size or past practices of discrimination, it considers to be disadvantaged. In 2013, the US federal government awarded 23.4 percent of its procurement spending to small businesses and 8.61 percent of its procurement spending to small businesses owned and controlled by ethnic minorities and women.[2] To obtain these levels of participation, the US regularly establishes subcontracting requirements on its federal procurement projects, which specify a percentage of the total award amount that should be given to preferred firms. 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. In this paper, I study how these subcontracting policies affect procurement outcomes.

A key feature of subcontracting requirements is that they require prime contractors to complete more of their projects with subcontractors from a common set of disadvantaged firms. I use a procurement auction model with endogenous subcontracting to show that this feature can mitigate cost increases associated with using more costly subcontractors. In particular, I model a project as a number of different tasks. Prime contractors can complete these tasks by using a mix of private resources and subcontractors from a shared pool of disadvantaged firms. I derive a prime contractor's bid in this environment as a strategic markup over its project costs, where the markup increases as prime contractors use more of their own private resources. With subcontracting requirements, prime contractors must use less of their private resources and more disadvantaged subcontractors, which lowers the amount of private information prime contractors have on their own project costs. Prime contractors respond by reducing their markups in their bids. The main finding in my paper is that the reduction in markups can be sufficiently high to leave the cost of procurement virtually unchanged, even if the additional subcontracting increases project costs.

I estimate an empirical version of the model with administrative highway procurement auction data from the New Mexico Department of Transportation (NMDOT) in order to evaluate their Disadvantaged Business Enterprise (DBE) Program. This program relies on subcontracting requirements to increase the representation of small businesses owned and controlled by socially and economically disadvantaged individuals – who are primarily ethnic minorities and women – on federal procurement projects. I find that New Mexico's past subcontracting requirements are responsible for a 12.7 percent increase in the amount of money awarded to

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[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.

DBE subcontractors yet only increased procurement costs by 0.3 percent. These results suggest that New Mexico's subcontracting requirements were not responsible for large increases in procurement costs.

I then use the model to compare subcontracting requirements with two alternative policies geared towards increasing DBE participation: a quota and a subsidy. I implement the quota by removing prime contractors' rights to subcontract below the DBE subcontracting requirement, which is currently possible under New Mexico's program; I design the subsidy as a payment from the NMDOT to prime contractors proportional to their DBE utilization. My analysis of these two policies reveals that New Mexico can achieve the same level of DBE participation at even lower costs of procurement with subsidies relative to subcontracting requirements and quotas. This outcome is a consequence of subsidies distorting the subcontracting decisions of low project cost prime contractors less than the other policies. At the level of DBE participation achieved under New Mexico's current subcontracting requirements, quotas result in larger amounts of money awarded to DBE subcontractors relative to the other policies. These results imply that quotas are best for governments seeking to increase DBE awards, while subsidies are best for governments aiming to reduce procurement costs.

My paper fits into the literature on subcontracting and how it affects firms and auction outcomes. Jeziorski and Krasnokutskaya (2014) study subcontracting in a dynamic procurement auction, and their model is closely related to the model in my paper. The main theoretical difference between their model and mine is that I allow for a project to have different tasks. By including this task feature, my model accounts for the possibility that the additional cost of using disadvantaged subcontractors when there are subcontracting requirements can vary with a project's task composition, which is reflective of many highway construction projects in practice. Additionally, their empirical application relies on calibrated parameters, whereas my empirical model, although less flexible with the tasks due to data limitations, allows me to identify and estimate all of its primitives. 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 different auction formats affect entry and subcontracting choices, 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.

There are additional papers within the subcontracting literature that focus on the relationship between prime contractors and their subcontractors and suppliers. In construction, Gil and Marion (2013) study how the relationships between prime contractors and their subcontractors shape firm entry and pricing

decisions. Papers in other industries include Kellogg (2011), Masten (1984), and Joskow (1987). My paper abstracts away from many of these more dynamic relationship issues and focuses on a firm's static incentive to subcontract with disadvantaged firms.

My paper's empirical application to DBE subcontracting requirements complements the literature on subcontracting-based 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 considering how prime contractors allocate shares of a project to DBE subcontractors and how subcontracting requirements alter those decisions. 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. My approach differs in that I use a model to back out a firm's cost components. The estimated cost components allow me to compare outcomes 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.

There are a variety of recent studies on similar preference programs in government procurement. Athey et al. (2013) study set-asides and subsidies for small businesses in US Forest Service timber auctions. They find that set-asides reduce efficiency and that a subsidy to small businesses is a more effective way to achieve distributional objectives. My results on quotas and subsidies for disadvantaged subcontractors are similar in that I find that subsidies are generally less costly for the government relative to quotas. Nakabayashi (2013) investigates set-asides for small and medium enterprises in Japanese public construction projects and finds that enough of these smaller enterprises would exit the procurement market in the absence of set-asides to increase the overall cost of procurement. Empirical papers on bid discounting, which is yet another type of preference program, include Krasnokutskaya and Seim (2011) and Marion (2007) who study a bid discount program for small businesses in California and Rosa (2016) who investigates bid discounts for residents in New Mexico. Hubbard and Paarsch (2009) use numerical simulations to explore how discounts affect equilibrium bidding.

The remainder of the paper proceeds as follows. Section 2 describes the NMDOT's procurement process and DBE Program. Section 3 shows how I model bidding and DBE subcontracting, and section 4 contains a numerical example from my model. Section 5 shows how I estimate an empirical version of the model, while section 6 contains my descriptive analysis and estimation results. Section 7 presents my counterfactual

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simulations; section 8 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 guide my modeling choices 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, the NMDOT summarizes each project's main requirements in an Invitation for Bids (IFB) document. This document contains information on each project's type of work, location, completion deadline, DBE subcontracting requirements (if applicable), and licensing requirements. I use the information in the IFB documents to construct my set of project-level observables.

Interested firms then request the full set of contract documents from the NMDOT and write a proposal for the completion of each project. In the contract documents, the NMDOT provides firms with an engineer-estimated cost of the project, which I refer to as the the project's engineer's estimate. I include the engineer's estimates as an additional variable in my set of project-level observables. The contract 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. I use data compiled by the NMDOT from the contract documents on the winning firm's DBE subcontractors to calculate the share of work allocated to DBE firms.

Firms submit their proposals to the NMDOT through a secure website prior to the date of bid opening. On the date of bid opening, the NMDOT evaluates all proposals and selects the firm that offers the lowest total price on all tasks as the winner.[3] I model this process as a first-price sealed-bid procurement auction.

2.2 DBE Certification and Subcontracting Requirements

To qualify as a DBE, a firm must show the NMDOT that it is a small business owned and controlled by socially and economically disadvantaged individuals, who are primarily ethnic minorities and women. Ownership requires that at least 51 percent of the firm be owned by these disadvantaged individuals, while

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[3]The NMDOT can reject the lowest bid if the lowest bidding firm fails to meet DBE subcontracting requirements or quality standards. For a more detailed description of the circumstances where the NMDOT will reject a low bid, see the NMDOT's Consultant Services Procedures Manual available at http://dot.state.nm.us/en/Program_Management.html.

control generally requires that disadvantaged individuals have the power to influence the firm's choices. The Small Business Administration, which is the federal agency that supports and manages small business programs, determines whether a firm qualifies as a small business in a particular industry by considering economic characteristics such as the size of the firm relative to the industry's average firm size. As part of the certification process, the NMDOT visits the offices and job sites of DBE applicants to verify their information. The NMDOT will also routinely check certified DBEs to ensure that they meet the eligibility requirements. Firms that attempt to participate in the DBE Program based on false information can be subject to administrative fines and suspension from federal contracting. There are a total of 235 qualified DBE firms as of April, 2016.[4]

As a recipient of federal funds, the NMDOT is also required to set an overall state goal for the utilization of qualified DBE firms on federally assisted construction contracts. The state expresses its DBE utilization goal as a percentage of total federal funds it awards to DBE firms and has historically been 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 set subcontracting requirements on individual projects, which, similar to the state goal, requires that prime contractors allocate a pre-specified percentage of the total award amount to DBE subcontractors.

In setting these requirements on individual contracts, the NMDOT takes a number of factors into consideration. In particular, the NMDOT bases their DBE subcontracting requirements on the type of work involved on a project, the project's location, and the availability of DBE subcontractors to perform the type of work requested on a project. Additionally, the NMDOT will only consider projects with both subcontracting opportunities and estimated costs of more than $300,000 eligible for DBE subcontracting requirements. Since those projects are the only ones eligible for subcontracting requirements, much of my empirical and counterfactual analysis focuses on those larger projects.

Once established, the NMDOT gives prime contractors a number of incentives to meet a project's subcontracting requirement. Although the requirement is not a binding quota, contractors who fall short of the requirement incur additional costs in the form of showing satisfactory effort to use DBE subcontractors to the NMDOT as well as having a higher probability of their bid rejected by the NMDOT. Moreover, a prime contractor that fails to meet a project's requirement can be fined according to the difference between the established goal and the achieved level of DBE participation. I model these costs as fines paid by prime

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[4]For additional information on the NMDOT's DBE Program, see the DBE Program Manual available at http://dot.state.nm.us/en/OEOP.html#c.

contractors who miss the subcontracting requirement.

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 the value of their services 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.

In the model, I represent the cost of using DBE subcontractors with an upward-sloping pricing function common to all prime contractors. Unfortunately, the New Mexico data does not keep track of the subcontractors used by bidders who do not win, so I cannot directly test whether DBE subcontractor utilization is common with the data. In other states that have similar DBE systems and that keep public records of DBE commitments on projects with subcontracting requirements, bidders rarely use different firms in satisfying the DBE subcontracting requirement. In a sample of lettings from Iowa, for example, 82.4 percent of lettings with subcontracting requirements and more than one bid had overlap in DBE subcontractors.[5] The advantage of using New Mexico over these states is that I also have data on DBE commitments without subcontracting requirements. This data variation allows me to separately identify all of my model's primitives.

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

In this section, I develop a theoretical model that formalizes the different channels through which DBE subcontracting requirements affect a prime contractor's bidding and DBE subcontracting decisions. My model is closely related to the subcontracting model proposed by Jeziorski and Krasnokutskaya (2014) but adds tasks and a policy that encourages the use of DBE subcontractors.[6]

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[5]This statistic comes from the Iowa Department of Transportation's January, 2011 letting, which is available at https://www.bidx.com/ia/letting?lettingid=11%2F01%2F19. Other lettings from Iowa have a similar pattern.

[6]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, which is typically used as a measure of the potential number

For each project, prime contractors decide how much work to give DBE subcontractors on each of the project's tasks and how much to bid. Prime contractors base their decisions on their non-DBE costs of completing the entire project, which includes work completed in house and by non-DBE subcontractors. My model also incorporates subcontracting requirements when set by the NMDOT.

3.1 Environment and Objective Function

Formally, N risk-neutral bidders compete against each other for the rights to complete a single, indivisible highway construction project. Bidders are ex-ante symmetric in that each bidder draws their cost of completing the entire project without DBE subcontractors, c_i, independently from the same distribution, F, with support on the interval $[\underline{c}, \overline{c}]$. This cost, which I refer to as a bidder's non-DBE cost, includes work done by the prime contractor and non-DBE subcontractors. Bidders know the realization of their own non-DBE cost and the distribution of non-DBE 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 consists of T tasks. Tasks are indexed by $t \in \{1, 2, \ldots, T\}$, and each task accounts for a fraction $\tau_t \in (0, 1]$ of the total project, where $\sum_{t=1}^{T} \tau_t = 1$. Given a particular task t, bidders choose a share of that task, $s_{i,t} \in [0, 1]$, to subcontract to DBE firms, which reduces their portion of the cost of completing that task from $\tau_t c_i$ to $\tau_t c_i (1 - s_{i,t})$. Under this formulation, the total share of the project subcontracted to DBE firms on task t is $\tau_t s_{i,t}$. I model a bidder's cost of using DBE subcontractors on task t as 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.[7] The total cost of using a DBE subcontracting share of $s_{i,t}$ on task t given τ_t is then $P_t(s_{i,t}; \tau_t)$, and I will now refer to this cost as a bidder's DBE cost (of task t). A limitation of placing this type of structure on the DBE subcontracting market is that it assumes away any type of private information that a bidder 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 contractors. Instead, each bidder has access to the same DBE subcontracting technology.

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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. As a result, the analysis targets bidding and subcontracting strategies rather than entry and capacity constraints.

[7]This pricing function represents the prices received by prime contractors from DBE subcontractors on a particular task through the quote solicitation process. Ideally, I would model the DBE subcontracting market 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 subcontractors, I can only use prices to infer the cost of using DBE subcontractors. For a discussion of the microfoundations of P_t, see appendix B.

Some of the NMDOT's highway construction projects are subject to DBE subcontracting requirements. Namely, for every prospective highway construction project, the NMDOT specifies a total share of the project, $\overline{s} \in [0,1]$, that is to be completed by DBE subcontractors, and this DBE subcontracting requirement is known to all bidders prior to any bidding or DBE subcontracting decisions. A choice of $\overline{s} = 0$ in this environment is analogous to not having a DBE subcontracting requirement.

I assume that the NMDOT enforces their subcontracting requirements through fines. These fines represent any additional costs to bidders who miss the subcontracting requirement, including any actual fines, the increased probability of bid rejection, and any additional effort required to show the NMDOT satisfactory effort to use DBE subcontractors. Formally, subcontracting requirements alters a bidder's optimal choice of DBE subcontracting and bidding through a fine function $\varphi : [0,1]^{T+1} \to \mathbb{R}^+$, which 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, I assume that φ is non-increasing, convex, and continuously differentiable in all of its arguments.

In sum, a bidder's optimization problem is

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

where $\boldsymbol{s}_i$ and $\boldsymbol{\tau}$ are vectors that collects the bidder's DBE share choices for each task and the fractions of the total project for each task respectively. A strategy in this environment is a $T + 1$-tuple that consists of a bid 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, I focus on symmetric Nash equilibria in bidding and DBE subcontracting; therefore, I drop the i subscript 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 the DBE subcontracting market allows all bidders to substitute between completing tasks with non-DBE resources and with DBE subcontractors. This substitution benefits the bidders in that increasing the DBE subcontracting share reduces their non-DBE portion of the cost of completing the contract; however, this substitution is costly in that it requires bidders to give up a portion of their profits to their DBE subcontractors. Another notable change is that DBE subcontracting creates a shared component in bidders' costs of completing the entire project, since all bidders have equal access to DBE subcontracting.

3.2 DBE Subcontracting Strategies

I begin my analysis of bidding and DBE subcontracting behavior by solving for the optimal DBE subcontracting share given a non-DBE cost realization and a DBE subcontracting requirement. I use the first-order conditions to characterize an optimal DBE subcontracting share $s_t(c_i; \overline{s}, \tau_t)$. My analysis of the second-order conditions is contained in the appendix; see appendix A.1.1. For an interior choice of $s_t(c_i; \overline{s}, \tau_t)$, the first-order conditions require that

$$\tau_t c_i = P_t'(s_{i,t}; \tau_t) + \varphi_{s_{i,t}}(\boldsymbol{s}_i; \overline{s}, \boldsymbol{\tau}), \tag{2}$$

where $\varphi_{s_{i,t}}(\boldsymbol{s}_i; \overline{s}, \boldsymbol{\tau})$ is the partial derivative of the fine function with respect to $s_{i,t}$. For bidders whose optimal choice is to never use DBE subcontractors on a particular task, the following condition must hold:

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

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

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

There are a couple of key properties of optimal DBE subcontracting. Similar to Jeziorski and Krasnokutskaya (2014), the optimal DBE subcontracting decision does not depend on the probability of winning the auction. Intuitively, subcontracting only affects a bidder's objective function through the payoff conditional on winning and does not directly affect the probability of winning. 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, one can reinterpret the optimal decisions of a bidder 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 $\boldsymbol{s}_i$.

Before moving into the bidding strategies, note the effect of DBE subcontracting requirements on DBE subcontracting decisions. With an interior choice of $s_t(c_i; \overline{s}, \tau_t)$, assigning a positive DBE subcontracting requirement on a project only affects the DBE subcontractor choice through the marginal fine rather than the fine's value. From a policy prospective, bidders are more likely to change their subcontracting behavior

if φ changes rapidly in s_t, implying that policies that impose larger marginal fines for missing the DBE subcontracting requirement are more effective in changing equilibrium DBE subcontracting shares.

3.3 Bidding Strategies

In addition to selecting a DBE subcontracting share, bidders must also decide on how to bid. To characterize that decision, I first separate a bidder's non-DBE cost of completing the project from its total cost of completing the project, which I will now refer to as its project cost. A bidder's project cost consists of its total non-DBE costs, total DBE costs, and any fines.[8] Formally, I define a bidder's project cost as

$$\phi\left(c_i; \overline{s}, \boldsymbol{\tau}\right) = \sum_{t=1}^{T} \left(\tau_t c_i \left(1 - s_t \left(c_i; \overline{s}, \tau_t\right)\right) + P_t \left(s_t \left(c_i; \overline{s}, \tau_t\right); \tau_t\right)\right) + \varphi\left(\boldsymbol{s}\left(c_i; \overline{s}, \boldsymbol{\tau}\right); \overline{s}, \boldsymbol{\tau}\right).$$

Substituting ϕ 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 a project cost rather than a non-DBE cost. This transformed optimization problem together with boundary condition $b\left(\overline{\phi}\right) = \overline{\phi}$ has a unique solution that is increasing in ϕ, given arguments from Reny and Zamir (2004), Athey (2001) and Lebrun (2006).[9] As a result, I focus on symmetric bidding strategies that are increasing in ϕ.

There is a tight relationship between a bidder's project cost and a bidder's non-DBE cost. In particular, observe that

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

where the above inequality uses the first-order conditions on DBE subcontracting to eliminate the extra terms in the derivative. Equation (5) demonstrates that the project cost is increasing in c_i whenever $s_t\left(c_i; \overline{s}, \tau_t\right) \in [0, 1)$ for at least one task and flat whenever $s_t\left(c_i; \overline{s}, \tau_t\right) = 1$ for all tasks. Intuitively, bidders with lower non-DBE costs should also have lower project costs unless their non-DBE costs are high enough that it is optimal to subcontract the entire project to DBE firms. Furthermore, this relationship implies that the bid function is increasing in c_i, except when $s_t\left(c_i; \overline{s}, \tau_t\right) = 1$ for all tasks.

Using an envelope theorem argument based on Milgrom and Segal (2002) and equation (5), I derive an expression for the optimal bid function in terms of non-DBE costs. Let $\boldsymbol{s}\left(c_i; \overline{s}, \boldsymbol{\tau}\right)$ be the vector of optimal DBE share decisions. Proposition 1 presents the bid function expression, with the details of its derivation

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

[9]Observe that $\overline{\phi} = \sum_{t=1}^{T} P_t\left(1; \tau_t\right) + \varphi\left(\boldsymbol{1}; \overline{s}, \boldsymbol{\tau}\right)$ is the project cost of a bidder that subcontracts the entire project to DBE firms, where $\boldsymbol{1}$ is a vector of ones of length T. I derive this expression from the previous result that the optimal DBE subcontracting share is increasing in c_i.

contained in appendix A.2.[10]

Proposition 1. *The optimal bid function is*

$$b\left(c_i; \overline{s}, \boldsymbol{\tau}\right) = \underbrace{\sum_{t=1}^{T} \tau_t \frac{\int_{c_i}^{\overline{c}} \left(1 - s_t\left(\tilde{c}; \overline{s}, \tau_t\right)\right) \left(1 - F\left(\tilde{c}\right)\right)^{N-1} d\tilde{c}}{\left(1 - F\left(c_i\right)\right)^{N-1}}}_{\text{Markup}}$$

$$+ \underbrace{\sum_{t=1}^{T} \left(\tau_t c_i \left(1 - s_t\left(c_i; \overline{s}, \tau_t\right)\right) + P_t\left(s_t\left(c_i; \overline{s}, \tau_t\right); \tau_t\right)\right) + \varphi\left(\boldsymbol{s}\left(c_i; \overline{s}, \boldsymbol{\tau}\right); \overline{s}, \boldsymbol{\tau}\right)}_{\text{Project Cost}}. \quad (6)$$

There are a couple of key features of the bid function. In particular, one can interpret the optimal bid function as a strategic markup[11] over project costs. An increase in the DBE subcontracting function on any one task necessarily reduces a bidder's markup and total non-DBE costs. Moreover, the fine function appears as an additive term in the bid function, meaning that bidders pass fines through to their bids.

3.4   The Role of DBE Subcontracting Requirements

Subcontracting requirements can introduce several interesting changes in equilibrium bidding and DBE subcontracting, which come from the features of the equilibrium bid and DBE subcontracting functions. I summarize those changes in the next proposition and corollaries and provide the proofs of each statement in appendix A.

Proposition 2. *For a given task t and a given non-DBE cost draw c_i, if $s_t\left(c_i; 0, \tau_t\right) \neq s_t\left(c_i; \overline{s}, \tau_t\right)$, then $s_t\left(c_i; 0, \tau_t\right) < s_t\left(c_i; \overline{s}, \tau_t\right)$.*

Proposition 2 says that on tasks where the policy can affect a bidder's 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 subcontractors to avoid incurring any fines. Therefore, prime contractors will increase the share of work given to DBE subcontractors on tasks

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[10]The NMDOT does not use reservation prices in its procurement auctions, so my 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, I follow 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.

[11]Technically, the markup term contains the bidder's markup and the markups of all non-DBE subcontractors. I will continue to refer to this term as the markup where this distinction does not cause confusion.

where using DBE subcontractors is sufficiently low priced. The next corollary addresses how subcontracting requirements affect project costs.

Corollary 1. *DBE subcontracting requirements weakly raise project costs.*

The intuition behind corollary 1 is that, in the absence of DBE subcontracting requirements, bidders will choose their shares of DBE subcontractors to extract the highest possible profits, which in this case is analogous to minimizing their project costs. As shown in proposition 2, subcontracting requirements can change DBE subcontracting decisions, and that change leads to higher project costs. The next corollary ties DBE subcontracting requirements to a bidder's markup.

Corollary 2. *DBE subcontracting requirements weakly lower markups.*

The proof of corollary 2 relies on propositions 1 and 2. In particular, the expression for the optimal bid function in proposition 1 implies that an increase in DBE subcontracting on any one task reduces the bidder's markup, while proposition 2 shows that DBE subcontracting requirements (weakly) increase total DBE subcontracting. From those two propositions, it immediately follows that DBE subcontracting requirements weakly lower markups. Intuitively, subcontracting requirements distort a bidder's DBE subcontracting decisions towards completing a project with more DBE subcontractors and less non-DBE resources. Since bidders can only markup components of their costs that are private and the cost of DBE subcontractors is common, that distortion leads to a reduction in markups.

4   Numerical Example

In this section, I turn to a numerical example to illustrate the main points of the theory. For this example, I assume that two prime contractors ($N = 2$) are competing for a single construction project. I assume that the prime contractors' non-DBE costs are distributed uniformly on the interval $[0, 1]$ and that the project consists of two tasks ($T = 2$), each amounting to 50 percent of the total work ($\tau_1 = \tau_2 = 0.5$). For simplicity, I assume that the pricing functions and the fine function are quadratic and that prime contractors are only fined if their total share of work going to DBE subcontractors is below the subcontracting requirement:

$$
P_t\left(s_{i,t}; \tau_t\right) = \frac{\xi_t \tau_t s_{i,t}^2}{2}
$$

$$
\varphi\left(s_{i,1}, s_{i,2}; \overline{s}, \tau_1, \tau_2\right) = \begin{cases} \frac{\lambda(\tau_1 s_{i,1} + \tau_2 s_{i,2} - \overline{s})^2}{2} & \text{if } \tau_1 s_{i,1} + \tau_2 s_{i,2} < \overline{s} \\ 0 & \text{if } \tau_1 s_{i,1} + \tau_2 s_{i,2} \geq \overline{s} \end{cases},
$$

where ξ_t and λ are coefficients that control the steepness of the pricing and fine functions respectively. Since tasks can vary in the cost of using DBE subcontractors and those differences are reflected in the steepness of the DBE pricing function, I set $\xi_1 = 1$ and $\xi_2 = 2$. This configuration of pricing coefficients means that it is less expensive for prime contractors to use DBE subcontractors on the first task relative to the second task. I set the fine coefficient, λ, to 3 so that the fine is sufficiently steep to change subcontracting behavior, and I set the subcontracting requirement to 30 percent ($\overline{s} = 0.3$) when it applies. Figure 1 contains plots of the two pricing functions and the fine function.
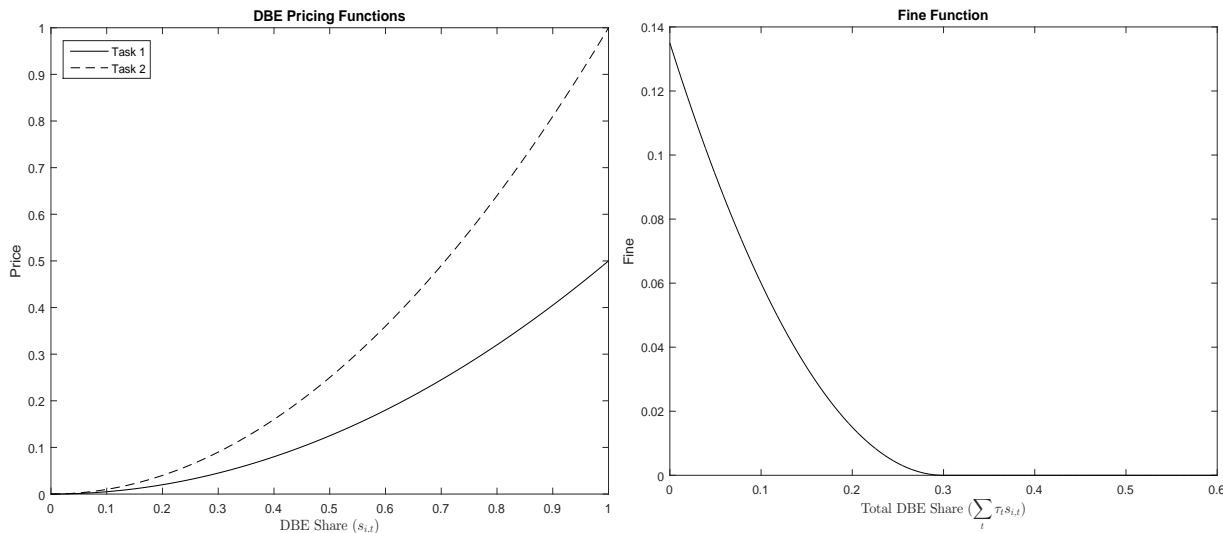

Figure 1: DBE Pricing and Fine Functions

I begin my analysis by first solving for the optimal DBE subcontracting shares as a function of non-DBE costs. To highlight the effects of subcontracting requirements, I perform this calculation twice: once when there is a requirement and once where there is no requirement. Figure 2 contains plots of these functions.

Subcontracting requirements lead to a couple of interesting changes to DBE subcontracting behavior. In particular, subcontracting requirements increase the share of work allocated to DBE subcontractors for prime contractors with lower non-DBE cost draws and leaves shares unchanged for prime contractors with higher non-DBE cost draws, which is consistent with proposition 2. Intuitively, prime contractors with lower non-DBE cost draws find it more profitable to use their own non-DBE resources instead of the relatively more expensive DBE subcontractors. The fine gives these contractors an extra incentive to increase their DBE shares, which is why DBE subcontracting is higher for them when there is a requirement. Prime contractors with higher non-DBE costs are more inclined to use DBE subcontractors to lower their project costs and may even subcontract above and beyond the requirement. When prime contractors do subcontract
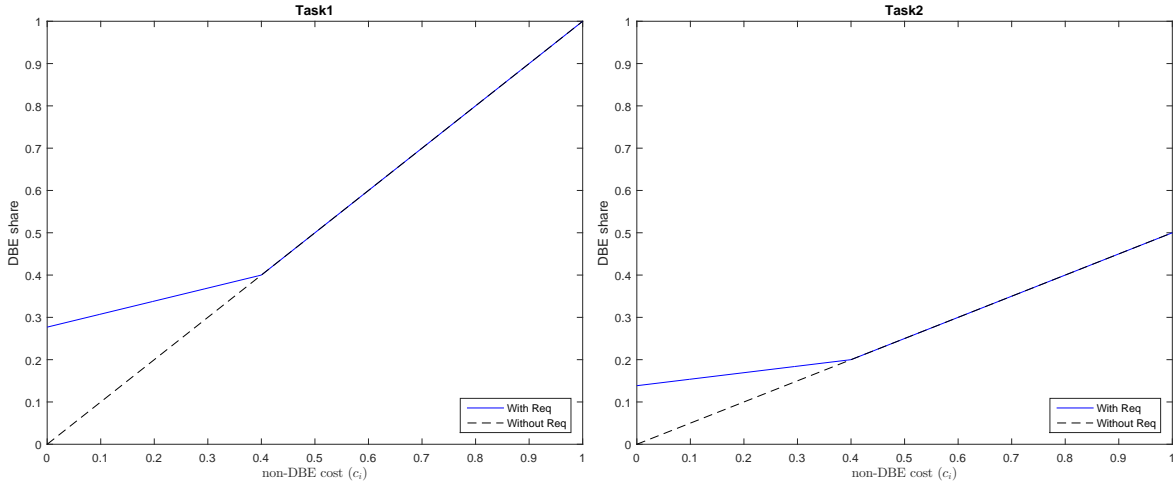
14

Figure 2: DBE Share Functions

above the requirement, the fine is no longer effective, so there is no change in DBE subcontracting behavior. Additionally, prime contractors affected by the subcontracting requirement use DBE subcontractors more on the first task relative to the second task, since DBEs are less costly on the first task.

Given the solutions for optimal DBE subcontracting, I next analyze equilibrium bidding with and without the subcontracting requirement. Specifically, I use equation (6) to obtain a solution for the equilibrium bids given the uniform assumption on non-DBE costs and the functional forms for the DBE pricing functions and the fine function. I plot these functions in figure 3. A striking feature of the bid functions is that bids are virtually unchanged with subcontracting requirements relative to without subcontracting requirements, even when prime contractors draw low non-DBE costs. For this range of non-DBE cost draws, the reduction in markups is sufficiently high to mitigate the cost of using more DBE subcontractors. Also note that firms that would subcontract beyond the requirement do not change their bidding behavior, which is why the bid functions overlap.

Taken together, the simulations demonstrate that subcontracting requirements can increase the share of work allocated to DBE subcontractors without substantially changing final cost of procurement. The requirement mainly affects prime contractors with low non-DBE costs, causing them to increase their usage of DBE subcontractors. With sufficiently high markups, increased DBE subcontracting only slightly changes optimal bidding, implying small changes in procurement costs.
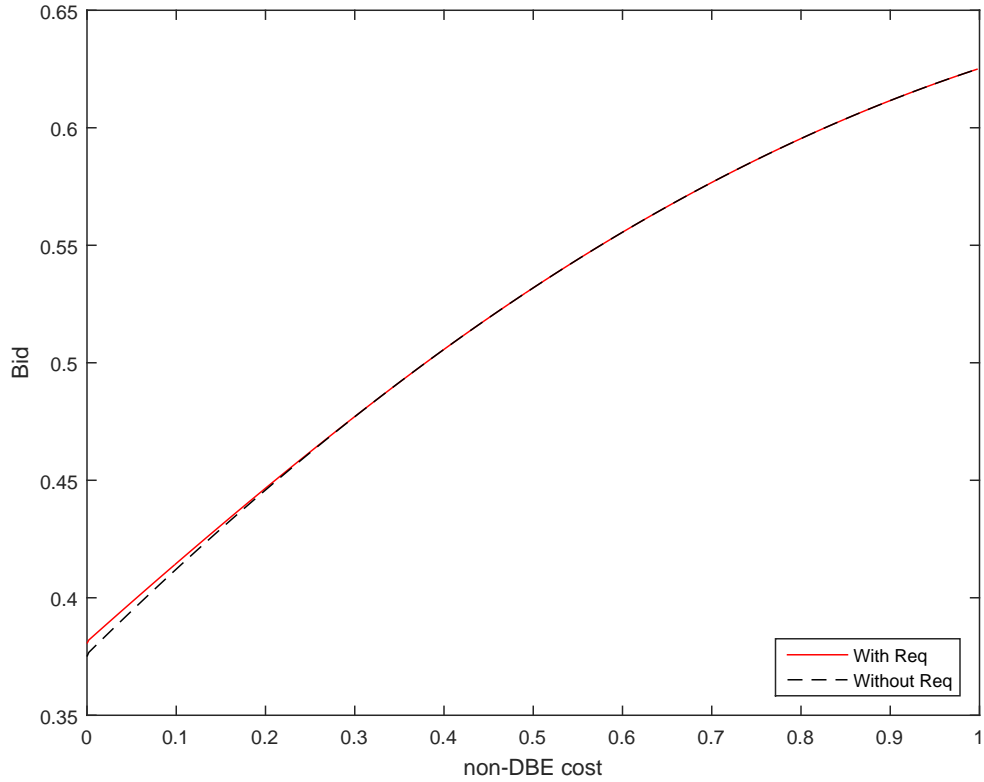
15

Figure 3: Bid Function

5   Empirical Model and Estimation

Although the theoretical model can account for a number of different ways in which subcontracting require-
ments can affect bidding and DBE subcontracting, it cannot be applied to the New Mexico data without
additional assumptions. In this section, I outline those assumptions and provide a description of the estima-
tion procedure. I end this section by discussing the sources of variation in the data that identify the empirical
model's parameters.

5.1   Simplifying Assumptions

The data is limited in that it does not have a complete description of the tasks required to complete each
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, I assume that each project can be combined
into one aggregate task. Under this assumption, prime contractors choose a total share of the project to
allocate to DBE subcontractors (s_i) and face an aggregate DBE pricing function ($P(\cdot)$). The first-order

conditions for DBE subcontracting of this simplified model is then

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

while the optimal bid function is

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

5.2 Parametric Assumptions

To account for a rich set of observed project characteristics while avoiding the curse of dimensionality, I estimate a parametric version of the simplified model. I assume that a project, indexed by w, is 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.

I use the project characteristic u_w to represent unobserved conditions in the DBE subcontracting market, such as the availability of DBE firms to act as subcontractors and the concentration of DBE subcontractors in a required task. Given that the NMDOT may have extra information on these unobservable characteristics when establishing a DBE subcontracting requirement, I allow u_w to depend on $\overline{s}_w$. Specifically, I assume the distribution of u_w follows a gamma distribution with a shape parameter of 1 and a scale parameter of $\sigma_u = \exp(\sigma_{u0} + \sigma_{u1} DBE\,req)$, where $DBE\,req = \overline{s}_w \times 100$.

I also parameterize the non-DBE cost distribution so that it is consistent with the theory. In particular, I assume that non-DBE costs 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 ψ is a vector of structural parameters that shift the non-DBE cost distribution and $\overline{c}_w$ is the project-specific upper bound on the non-DBE cost distribution.[12] I use the variable $\overline{c}_w$ to get the upper limit of integration when solving for the equilibrium bids in equation (8), and I construct $\overline{c}_w$ by using the highest bid normalized by the engineer's estimate in the sample. Specifically, let $\hat{x}_w \in \boldsymbol{x}_w$ be a project's

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

engineer's estimate, 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 $\overline{c}_w = k\hat{x}_w$.[13]

I use parametric functional forms for the pricing and fine functions similar to the ones used by Jeziorski and Krasnokutskaya (2014). In particular, I assume that the DBE pricing function and fine function take the following functional forms:

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

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

The hyperbolic term in equation (9) prevents firms from subcontracting entire projects to DBE subcontractors. In the data, no firms select a DBE share of 100%, so I use this functional form to mirror that empirical fact. The scaling by $\hat{x}$ in P and φ ensures that the problem scales properly, since projects vary in size; the scaling by s_i in P ensures that a prime contractor that allocates none of the project to DBE subcontractors does not have a DBE cost. I use a piecewise functional form in equation (10) so that only prime contractors who fail to meet the DBE subcontracting requirement 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. I present these constraints in appendix C.1.

5.3 Estimation

Given a set of structural parameters, my empirical model generates unique solutions for DBE subcontracting shares and equilibrium bids. The final set of structural parameters are the ones whose predictions are closest to the outcomes observed in the data. I obtain these parameters with an indirect inference estimator, which matches the parameters from an auxiliary model estimated with the true data and simulated data.[14]

I simulate the data in several steps. Given a guess for the structural parameters $\theta = (\psi, \sigma_c, \sigma_u, \alpha_0, \alpha_1, \alpha_2, \alpha_3, \gamma)$, I first simulate N_w non-DBE costs for each auction. Since bids are increasing in non-DBE costs, I

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[13]Observe 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 subcontractors, since the boundary condition on bids is in terms of project costs rather than non-DBE costs. While I do not observe the share of the project allocated to DBE subcontractors for losing bidders, the winning bidder in the auction I use to set k has a DBE share of 0, which makes this approximation plausible.

[14]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. I use methods from this extended version in estimating the empirical model.

take the lowest of the N_w non-DBE costs as the non-DBE cost of the winning bidder. Let W denote the total number of auctions observed in the data and H the total number of simulations. In total, I select WH non-DBE costs from the $\sum_w N_w H$ simulated non-DBE costs. Next, I calculate the equilibrium DBE subcontracting shares using the first-order conditions on DBE subcontracting in equation (7). To account for the corner solutions, I take the maximum of 0 and the DBE shares obtained from solving the first-order conditions for s_i; the other corner solution is ruled out by the functional form of $P(s_i)$. With the shares calculated, I solve for the equilibrium winning bids using equation (8). This step requires an approximation of the optimal DBE share function, so I use polynomial approximations obtained by fitting a polynomial on a grid of optimal DBE shares for each auction.

To then implement the indirect inference estimator, I need to select an auxiliary model. In general, the auxiliary model should be straightforward to estimate and account for the endogenous outcomes. The two endogenous outcomes are the equilibrium bids and DBE subcontracting shares, so I use a linear ordinary least squares (OLS) regression of the log-winning bid and a linear OLS regression of the winning bidder's DBE subcontracting share as the two components of my auxiliary model. Specifically, if s_w is the share of the project the winning bidder allocates to DBE subcontractors in auction w and b_w is the winning bidder's bid in auction w, then my auxiliary model for the DBE share and winning bid is

$$
s_w = \left[\begin{array}{c} \boldsymbol{x}_w \\ \overline{s}_w \end{array} \right]' \beta_s + \epsilon_{sw}
$$

$$
\log(b_w) = \left[\begin{array}{c} \boldsymbol{x}_w \\ \overline{s}_w \end{array} \right]' \beta_b + \epsilon_{bw},
$$

where β_s are the parameters of the DBE share regression, β_b are the parameters of the winning bid regression, ϵ_{sw} is the error term on the DBE share regression, and ϵ_{bw} is the error term on the winning bid regression.

I use a Wald criterion function to match the true data to the simulated data. The indirect inference structural parameter estimates, $\hat{\theta}$, are then the solution the following optimization problem:

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

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. In

practice, I use the indirect inference estimator's optimal weight matrix as the weighting matrix, and I use the estimator's asymptotic distribution to calculate standard errors. For a detailed explanation of the optimal weight matrix and standard errors, see appendix C.2.

5.4 Parametric Identification

I conclude this section by discussing the variation in the data that identifies the model's structural parameters. These parameters are the mean and standard deviation of the non-DBE cost distribution (ψ and σ_c), the parameters of the observed components of the DBE pricing function ($\alpha_0, \alpha_1, \alpha_2$ and α_3), the parameters of the unobserved component of the DBE pricing function (σ_{u0} and σ_{u1}), and the fine function parameter (γ).

In the data, I observe projects without subcontracting requirements where prime contractors use no DBE subcontractors. The bids on these projects allow me to identify the non-DBE cost distribution parameters, since the bid function does not depend on the DBE pricing or fine functions when there are no DBE subcontractors and no subcontracting requirements.

From there, I can identify the parameters of the observed and unobserved parts of the DBE pricing function from two types of projects: projects with no subcontracting requirements and projects with subcontracting requirements where prime contractors exceed the subcontracting requirement. Given the non-DBE cost distribution parameters, the variation in bids and DBE shares on these projects correspond to changes in the DBE pricing function. I observe additional variation in bidding and DBE subcontracting between these two types of projects, and this variation allows me to identify the σ_{u1} parameter – which accounts for the possibility that the NMDOT assigns subcontracting requirements when it is less costly. Put differently, if firms tend to use more DBE subcontractors when there is no requirement, then the model would suggest that the NMDOT uses subcontracting requirements when DBE subcontractors are more costly.

The last parameter that needs to be identified is the fine parameter, γ. Given the non-DBE cost distribution parameters and DBE pricing function parameters, I identify γ from the bids and DBE shares of 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 the model attributes differences in bidding and subcontracting between prime contractors who meet and do not meet the requirement to γ.

6 Empirical Analysis

In this section, I perform the empirical analysis on the procurement data from New Mexico. My analysis begins with a description of the data and variables. I then present summary statistics and descriptive regressions to highlight the bidding and DBE subcontracting patterns present in the data. Finally, I provide the structural parameter estimates and a discussion of the model's fit.

6.1 Data Description and Variables

The data contains 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, I do not include contracts won by DBE prime contractors.[15] I construct the subcontracting portion of the data 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 each subcontractor's DBE status and individual award amount.

I augment the SHARE data with data on contract characteristics. In particular, I include 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 to complete each project, an engineer's estimated cost of completing each project, and the expected number of days needed to complete each project in the set of observable project characteristics. I gather this data 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.

I define the complete set of variables observed in the full data set as follows. *DBE share* is the percentage share of the total project awarded to DBE subcontractors. *Engineer's estimate* an engineer's estimated cost of a project, which 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, which are specified in the IFB documents and are used as a measure of how easily a contract can use subcontractors.[16] *Working days* are the number of days a given project is expected to take to complete, and *licenses* refers to the

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[15] My 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.

[16] See appendix G for an example of subprojects.

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 the 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.

I use additional observables 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. I separate the type of work requested for each project into six different categories: road work, bridge work, lighting, safety work, stockpiling, and other. I use the other category as the reference class.

6.2   Summary Statistics

Table 1 presents the summary statistics from the entire sample of NMDOT highway construction contracts. I divide projects 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: 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	

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 subcontracting requirements allocate 4.9 percentage points more to DBE subcontractors relative to eligible projects without subcontracting requirements. Despite these differences, projects with subcontracting requirements

tend to attract a similar number of bidders as eligible projects without subcontracting requirements, and on projects with requirements, many of the prime contractors comply with the requirement – allocating an average of 5.0 percentage points more than the required amount to DBE subcontractors.

6.3   Descriptive Regressions

In order to explore bidding patterns in the data, I run OLS regressions of the log-winning bids on the covariates collected from the NMDOT bidding data. Table 2 reports regression coefficients. The main parameter of interest is the coefficient on the DBE requirement variable, since 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. I capture the competitive bidding environment in the second column by the number of planholders and the number of bidders, while I include 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 to account for a project's proposed location. Column (3) adds month and year fixed effects as a control for seasonality. I repeat these regression specifications in columns (4) - (6) for a sample limited to projects eligible for DBE subcontracting requirements.

The regressions indicate that the winning bids are uncorrelated with DBE subcontracting requirements: across all specifications, the coefficient on the DBE requirement variable is small and statistically insignificant.[17] These results suggest that DBE subcontracting requirements are not associated 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 subcontracting. To address this question, I conduct a regression analysis of the percentage of projects allocated to DBE subcontractors by winning contractors by using the same six regression specifications as the winning bid regressions. I report the results in table 3.

Unlike the winning bid regressions, DBE subcontracting requirements have a positive and significant

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[17]Observe that these coefficients will be biased if there are unobservable factors that affect both bidding (later, 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. My empirical model explicitly accounts for this type of bias because it allows the subcontracting requirements to affect the price of using DBE subcontractors through unobservable factors.

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.

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 bids, are associated with their goal of increasing the utilization of DBE firms.[18]

Evidence that Higher DBE Shares Reduce Markups

My final piece of descriptive evidence addresses how the share of work allocated to DBE subcontractors relates to firm markups. In the model, increasing the number of competing bidders affects bids by reducing markups. The share of work given to DBE subcontractors also reduces markups, so the reduction in bids due to an increase in the number of competing bidders should be attenuated by amount of work assigned to DBE

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[18]A property of DBE subcontracting from the model, which is shown in appendix A, is that the total share of work given to DBE subcontractors is non-decreasing in c_i. This property can potentially be rejected by the data if bidders who submit higher bids choose lower DBE subcontracting shares, since bids are also increasing in c_i for $s(c_i; \bar{s}) \in [0, 1)$. Although the data cannot directly address this issue, I can test this property by using bids as a proxy for non-DBE costs in DBE subcontracting regressions. When included in a DBE subcontracting regression, the coefficient on the submitted bids is positive, suggesting that DBE subcontracting shares are associated with higher non-DBE costs.

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)	(0.688)		(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.

subcontractors. 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 subcontractors; a positive coefficient indicates that the share of work given to DBE subcontractors 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, I perform regressions of the log-winning bid on the project-level covariates, with an additional control for the DBE share and 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.

I present the results for the entire sample of winning bids and the winning bids on projects eligible for DBE subcontracting requirements 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

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.

utilization may work to reduce 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. I find that winning bids are uncorrelated with DBE subcontracting requirements and that DBE subcontracting requirements are associated with higher DBE shares. These two results appear to be contradictory given the expected increase in procurement costs associated with using disadvantaged subcontractors, motivating the need to investigate the channels proposed in the theoretical model. Finally, I find evidence that the share of work given to DBE subcontractors reduces firm markups, which is consistent with the implications of the model.

6.4 Structural Parameter Estimates

Next I turn to the parameter estimates from the empirical model. I assume that the distribution of log-non-DBE costs are 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, I only use projects eligible for DBE subcontracting requirements in the data.

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

	Coefficient	Standard Error
Constant	0.776	0.278
log(Engineer's Estimate)	0.922	0.012
log(Length + 1)	0.041	0.011
log(Planholders)	0.043	0.099
log(Subprojects)	0.080	0.021
Licenses	0.038	0.015
log(Working Days)	0.009	0.012
Federal Highway	-0.017	0.014
Urban	-0.015	0.020
District 2	-0.069	0.020
District 3	-0.060	0.021
District 4	-0.002	0.028
District 5	-0.044	0.023
District 6	-0.065	0.021
Bridge work	-0.007	0.025
Lighting	-0.065	0.058
Road Work	0.043	0.028
Safety Work	-0.013	0.028
Stockpiling	0.162	0.063
σ_c	0.261	0.112

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

I present the results for the non-DBE cost distribution parameter estimates in table 5. A firm's non-DBE cost is affected by a number of observable factors. In particular, I find that non-DBE costs are heavily influenced by the engineer's estimate; a one percent increase in the engineer's estimate corresponds to a 0.92 percent non-DBE cost increase, and this coefficient is statistically significant. Although much of a firm's non-DBE cost is driven by the engineer's estimate, other observable project characteristics can influence the mean of the log-non-DBE cost distribution. For example, a project's district ranges from decreasing non-DBE costs by 6.9 percent to 0.2 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 non-DBE costs by 6.5 percent to increasing non-DBE costs by 19.6 percent relative to projects classified as other.

The second set of parameter estimates include the parameters of the DBE pricing function and the fine function. I summarize these estimates in table 6. Higher DBE subcontracting requirements are associated with lower DBE pricing shocks, implying that the NMDOT sets these requirements when DBEs are more readily available. The DBE pricing function parameters imply that – when the level of u_w, the number of subprojects, and the level of the DBE subcontracting requirement are all fixed at their respective means on DBE-eligible projects – choosing a DBE subcontracting share of 1 percent requires a payment of 1.15

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

	Coefficient	Standard Error
σ_u		
Constant	0.333	0.331
DBE Req (%)	-0.186	0.059
Pricing Constant (α_0)	0.171	0.120
s_i (α_1)	0.518	0.316
$\frac{s_i}{1-s_i}$ (α_2)	0.637	0.300
1/Subprojects (α_3)	0.122	0.044
Fine Parameter (γ)	7.371	30.477

Note: Parameter estimates for the DBE pricing and fine functions. The standard deviation of DBE pricing shocks is modeled as $\sigma_u = \exp(\sigma_{u0} + \sigma_{u1} DBE\,req)$, where $DBE\,req$ is the level of the DBE subcontracting requirement.

percent of the project's engineer's estimate 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 five percent is about 1.8 percent of the project's engineer's estimate. For the average engineer's estimate on projects with DBE subcontracting requirements, this fine amounts to about $101,900.

6.5 Model Fit

I evaluate the model's fit 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 4 contains histograms comparing these two outcomes. In these histograms, the red lines represent the density of the simulated DBE shares, the blue lines represent the density of the simulated winning bids, and the black lines represent the density of the actual DBE shares and bids. I report winning bids in logs for visual clarity.

The model fits the winning bids fairly well but has difficulty replicating some of the distribution of DBE shares. The model overpredicts DBE shares of zero and underpredicts DBE shares between 0.05 and 0.10. 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.

To then compare how the model fit differs with DBE subcontracting requirements, I calculate the simulated and actual average DBE shares and winning bids for projects with and without DBE subcontracting
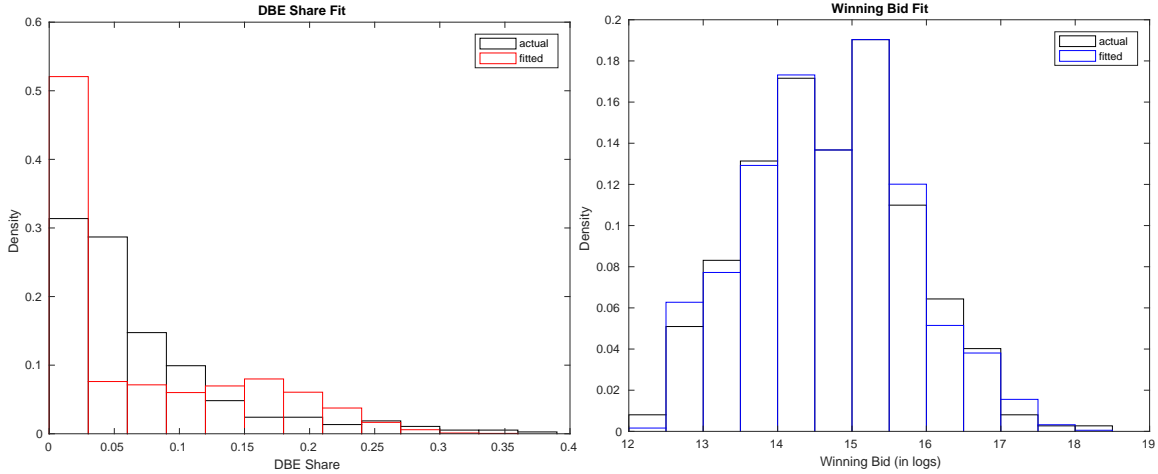
Figure 4: DBE Share and Winning Bid Outcome Fit

Note: Histograms of the actual and predicted DBE shares and Winning bids. 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.

requirements. I present the results in table 7. The model moments match these data moments reasonably well. The model's average DBE subcontractor shares are within 0.12 percentage points of the true average DBE subcontractor shares, and the model's average winning bids are within $140,000$ of the average winning bids in the data.

Table 7: Model Fit

	With Req.		W/o Req.	
	Actual	Predicted	Actual	Predicted
DBE Share (%)	9.15	9.05	4.30	4.18
Winning Bid (in Millions)	5.26	5.12	3.71	3.76

Note: The predicted and actual average winning bid and average DBE shares.

7   Counterfactual Analysis

I use the model's parameter estimates to predict counterfactual bidding and DBE subcontracting decisions under a variety of different policy alternatives. I first investigate changes in New Mexico's past subcontracting requirements; this exercise allows me to evaluate how subcontracting requirements affected past procurement outcomes. I then explore other policies aimed at encouraging the use of DBE subcontractors. In particular, I consider various quota and a subsidy policies and compare their outcomes with the outcomes obtained

with subcontracting requirements. In order to be consistent with the projects that New Mexico sees fit for government intervention, I only use projects with positive DBE subcontracting requirements in my analysis.

7.1 Counterfactual Subcontracting Requirements

The level of the DBE subcontracting requirements can vary from state to state and will impact how prime contractors use DBE subcontractors. To investigate how different levels of DBE subcontracting requirements would have affected New Mexico's procurement auctions, I simulate a range of different auction outcomes under a variety of different subcontracting requirements, including an elimination of all subcontracting requirements. My analysis in this section focuses on percent changes to the existing DBE subcontracting 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 past subcontracting requirements. The reported policy experiments include outcomes from the model simulated under a 50 percent increase in the DBE subcontracting requirement, no change in the DBE subcontracting requirement, a 50 percent decrease in the DBE subcontracting requirement, and an elimination of all subcontracting requirements.

I report the averages of six auction outcomes for each policy experiment. *DBE Share* is the simulated share of work going to DBE subcontractors, while *Winning Bid* refers to the simulated winning bid. *Project Cost* corresponds to the simulated project costs, and *Markup Reduction* is the dollar value of the reduction in markups associated with using DBE subcontractors. Theoretically, the markup reduction outcome coincides with the expression $\frac{\int_{c_i}^{\overline{c}} s(c_i)(1-F(\tilde{c}))^{N-1}d\tilde{c}}{(1-F(c_i))^{N-1}}$. *DBE Cost* is the portion of the winning bid that is paid to DBE subcontractors, and *Non-DBE Profits* is the markup term, which contains the prime contractor's and non-DBE subcontractor's profits.

Table 8: Counterfactual Goal Levels

	Increase (50%)	Baseline	Decrease (50%)	Elimination
DBE share (%)	9.68	9.05	8.60	8.42
Winning Bid (in 1000s)	5132.23	5116.78	5106.33	5103.56
Project Cost (in 1000s)	4328.02	4307.12	4292.97	4287.33
Markup Reduction (in 1000s)	108.85	103.39	99.69	96.82
DBE Cost (in 1000s)	354.41	314.10	288.79	278.71
Non-DBE Profits (in 1000s)	804.20	809.66	813.36	816.23

Note: Average auction outcomes for different requirement levels on auctions with DBE subcontracting reqirements. Effective costs are the costs to complete the entire project, which accounts for DBE subcontracting. Markup reduction is the dollar value of markups non-DBE firms lose as a result of DBE subcontracting. DBE cost is the average simulated DBE cost, and non-DBE profits are the profits of the winning prime contractor and its non-DBE subcontractors.

I display the results from the policy experiments in table 8. As a general trend, increasing the subcon-

tracting requirements decreases non-DBE profits, while the remaining outcomes increase. To provide some intuition, the increase in the requirements gives prime contractors an incentive to use more DBE subcontractors, and more DBE subcontractors result in higher payments to DBE firms. The increased payments leads to higher project costs, lower non-DBE profits, and higher winning bids. These effects are modest, though, since the fine function only affects the decisions of prime contractors that would otherwise subcontract below the DBE subcontracting requirement. Conversely, DBE subcontracting has a more pronounced effect on non-DBE profits. At New Mexico's past requirement levels, DBE subcontracting reduced average markups by $103,390$ or 11.3 percent.

To evaluate New Mexico's subcontracting requirement policy, I compare the baseline model's predictions to the predictions of the model when there are no DBE subcontracting requirements. These simulations predict that New Mexico's past requirements resulted in a 0.6 percentage point (or 7.5 percent) increase in the average share of work allocated to DBE subcontractors and a $35,390$ (or 12.7 percent) increase in the average money awarded to DBE subcontractors. These increases correspond to a $13,220$ (or 0.3 percent) increase in the average procurement cost and a $6,570$ (or 0.8 percent) decrease in average non-DBE firm profits.

7.2 Counterfactual Quotas

So far, my analysis shows that using fines to enforce DBE subcontracting requirements can lead to higher DBE subcontracting shares. The fine, however, does not guarantee that prime contractors fulfill the subcontracting requirements, since prime contractors can miss the requirement and pay the corresponding fee. In contrast, quotas ensure that prime contractors meet the requirement and can therefore lead to different auction outcomes relative to fines. To explore how outcomes would change under a quota, I re-simulate the auctions with the additional constraint that prime contractors must meet the quota, and for simplicity, I fix the quota level across all simulated auctions.

Table 9: Counterfactual Quota Levels

	0% Quota	5% Quota	10% Quota	15% Quota	20% Quota
DBE share (%)	8.42	10.52	13.09	16.28	20.34
Winning Bid (in 1000s)	5103.56	5172.63	5254.43	5353.97	5478.21
Project Cost (in 1000s)	4287.33	4373.41	4476.02	4601.09	4757.13
Markup Reduction (in 1000s)	96.82	113.83	134.64	160.18	191.98
DBE Cost (in 1000s)	278.71	452.30	666.72	926.48	1251.94
Non-DBE Profits (in 1000s)	816.23	799.22	778.41	752.88	721.08

Note: Average auction outcomes for different quota levels on auctions with DBE subcontracting reqirements.

Table 9 summarizes the outcomes for different quota levels. As expected, quotas lead to higher average shares of work completed by DBE subcontractors and become more binding at higher levels, since the average share is closer to the quota level. Similar to subcontracting requirements enforced by fines, higher quota levels lead to higher winning bids, higher project costs, and lower non-DBE profits. Quotas appear to be more effective than fines in increasing DBE participation, though. In fact, a uniform 5 percent quota leads to higher DBE subcontracting shares than a 50 percent increase in all DBE subcontracting requirements (which corresponds to an average subcontracting requirement of 6.3 percent).

7.3 Counterfactual Subsidies

As an alternative to enforcing subcontracting requirements, the NMDOT can increase DBE subcontracting shares by subsidizing DBE utilization. To investigate how subsidies would affect NMDOT procurement auctions, I simulate the auction outcomes under the assumption that the government subsidizes a share of the DBE costs. That is to say, rather than facing a DBE pricing function of $P(s_i)$, prime contractors now face a subsidized pricing function of $(1 - sub) P(s_i)$, where $sub \in [0, 1]$ is the fraction of the total DBE cost paid by the government. To track the subsidy's cost, I include *Subsidy Cost* and *Procurement Cost* as additional outcome variables, where *Subsidy Cost* is the average cost of the subsidy and *Procurement Cost* is the average cost of the subsidy added to the average winning bid.

Table 10: Counterfactual Subsidy Levels

	0% Subsidy	5% Subsidy	10% Subsidy	15% Subsidy	20% Subsidy
DBE share (%)	8.42	9.30	10.30	11.42	12.69
Winning Bid (in 1000s)	5103.56	5079.47	5051.96	5020.46	4984.26
Project Cost (in 1000s)	4287.33	4272.35	4255.05	4235.01	4211.69
Markup Reduction (in 1000s)	96.82	105.94	116.15	127.61	140.49
DBE Cost (in 1000s)	278.71	321.52	371.88	431.18	504.16
Non-DBE Profits (in 1000s)	816.23	807.11	796.91	785.44	772.56
Subsidy Cost (in 1000s)	0	16.08	37.19	64.68	100.83
Procurement Cost (in 1000s)	5103.56	5095.54	5089.15	5085.14	5085.09

Note: Average auction outcomes for different subsidy levels on auctions with DBE subcontracting reqirements.

Table 10 contains the results from the subsidy simulations. As is evident from the table, subsidies increase the average share of projects awarded to DBE subcontractors but are associated with lower winning bids. Intuitively, the subsidy makes DBE subcontractors cheaper, which encourages prime contractors to use them to obtain lower project costs. Increased DBE subcontractor utilization also leads to lower markups, and the combination of lower markups and lower project costs results in lower average equilibrium bids. Subsidies

also lead to lower non-DBE profits, which comes from prime contractors using more DBE subcontractors instead of either their own resources or non-DBE subcontractors.

A more counterintuitive result with subsidies is that they produce lower average procurement costs. This outcome is possible because subsidies are less likely to affect the most efficient[19] prime contractor's DBE subcontracting decisions yet make every competing firm more competitive. To illustrate this point with an example, consider a firm that is so efficient that it would never use DBE subcontractors – even with the subsidy. If that firm wins, there would be no subsidy cost, but the firm would have to lower its markup to compete with the other firms that can now obtain lower project costs with the subsidy.[20]

7.4 Comparing Quotas and Subsidies

With the set of outcomes established for different quota and subsidy levels, I now shift my analysis towards comparing these policies. In particular, I compare outcomes under a subsidy and a quota constrained to match the average DBE share obtained by the past subcontracting requirements. I calculate these subsidy and quota levels by using cubic splines to interpolate the non-simulated outcomes.

Table 11: Policy Comparisons

	Quota	Subsidy
Δ Winning Bid (%)	0.156	-0.595
Δ DBE Cost (%)	5.187	-1.585
Δ Non-DBE Profits (%)	0.178	0.005
Δ Procurement Cost (%)	0.156	-0.375

Note: Percent change in the average auction outcomes for policies that achieve the baseline average DBE subcontracting share.

Table 11 contains the policy comparisons. In general, many of the outcomes under subsidies and quotas are similar to the outcomes with subcontracting requirements. Subsidies result in lower winning bids, higher non-DBE profits, and lower procurement costs relative to subcontracting requirements, but subsidies also result in lower payments to DBE subcontractors. These results are intuitive, since subsidies distort more efficient prime contractors' DBE subcontracting decisions less than subcontracting requirements do, and more efficient prime contractors are more likely to win. Relative to subcontracting requirements and subsidies, quotas lead to higher payments to DBE subcontractors because prime contractors must use the specified share of DBEs instead of paying the fine or not using the subsidy, even if DBEs are unusually more costly. Taken together, these results suggest that quotas are appropriate for governments aiming to increase the

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[19]Efficiency refers to a prime contractor's non-DBE cost. A more efficient prime contractor has a lower non-DBE cost.
[20]I explore this result using simulations in the appendix; see appendix F.

amount of money given to DBE subcontractors, while subsidies are best for governments pursuing policies with lower procurement costs.

8   Conclusion

This paper theoretically and empirically examines how subcontracting requirements affect government procurement auctions. The subcontracting policy requires that prime contractors select subcontractors from a common pool of preferred firms, leading to a shared component in their project costs. Theoretically, this shared cost component reduces markups, and the reduction in markups can be sufficiently high to mitigate cost increases from using more costly subcontractors.

The policy experiments illustrate the impact of subcontracting requirements on procurement in New Mexico. I estimate that New Mexico's past subcontracting requirements increased the money given to DBE subcontractors by 12.7 percent, increased procurement costs by only 0.3 percent, and decreased non-DBE profits by only 0.8 percent. These results suggest that New Mexico's subcontracting requirements, although effective in increasing DBE subcontractor utilization, was not responsible for large increases in procurement costs.

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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:

$$-P_t''\left(s_{i,t};\tau_t\right) - \varphi_{s_{i,t}s_{i,t}}\left(\boldsymbol{s}_i;\overline{s},\boldsymbol{\tau}\right) < 0,$$

where $\varphi_{s_{i,t}s_{i,t}}\left(\boldsymbol{s}_i;\overline{s},\boldsymbol{\tau}\right)$ is the partial derivative of $\varphi_{s_{i,t}}\left(\boldsymbol{s}_i;\overline{s},\boldsymbol{\tau}\right)$ with respect to $s_{i,t}$. Observe that this condition will be satisfied for a φ 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

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

After some algebraic manipulation, the above equation reduces to

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

which is increasing given the second-order conditions.

A.2   Derivation of the Bid Function (Proposition 1)

I derive the bid function from an envelope theorem argument. In particular, the profit a bidder gains from a non-DBE cost realization c_i is

$$\Pi\left(c_{i};\overline{s},\boldsymbol{\tau}\right) = \tag{11}$$

$$\left(b\left(c_{i};\overline{s},\boldsymbol{\tau}\right) - \sum_{t=1}^{T}\left(\tau_{t}c_{i}\left(1 - s_{t}\left(c_{i};\overline{s},\tau_{t}\right)\right) + P_{t}\left(s_{t}\left(c_{i};\overline{s},\tau_{t}\right);\tau_{t}\right)\right) - \varphi\left(\boldsymbol{s}\left(c_{i};\overline{s},\boldsymbol{\tau}\right);\overline{s},\boldsymbol{\tau}\right)\right)$$
$$\times\left(1 - F\left(c_{i}\right)\right)^{N-1}.$$

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

$$\Pi\left(c_{i};\overline{s},\boldsymbol{\tau}\right) = \max_{\{b_{i},\boldsymbol{s}_{i}\}}\left(b_{i} - \sum_{t=1}^{T}\left(\tau_{t}c_{i}\left(1 - s_{i,t}\right) + P_{t}\left(s_{i,t};\tau_{t}\right)\right) - \varphi\left(\boldsymbol{s}_{i};\overline{s},\boldsymbol{\tau}\right)\right)\left(1 - F\left(b^{-1}\left(b_{i}\right)\right)\right)^{N-1}.$$

Apply the envelope theorem to get[21]

$$\left.\frac{d}{dc}\Pi\left(c;\overline{s},\boldsymbol{\tau}\right)\right|_{c=c_{i}} = \sum_{t=1}^{T}\tau_{t}\left(s_{t}\left(c_{i};\overline{s},\tau_{t}\right) - 1\right)\left(1 - F\left(c_{i}\right)\right)^{N-1}.$$

Integrate the above expression to get another expression for $\Pi\left(c_{i};\overline{s},\boldsymbol{\tau}\right)$:

$$\Pi\left(c_{i};\overline{s},\boldsymbol{\tau}\right) = \Pi\left(\overline{c};\overline{s},\boldsymbol{\tau}\right) + \sum_{t=1}^{T}\tau_{t}\int_{c_{i}}^{\overline{c}}\left(1 - s_{t}\left(\tilde{c};\overline{s},\tau_{t}\right)\right)\left(1 - F\left(\tilde{c}\right)\right)^{N-1}d\tilde{c}. \tag{12}$$

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

It is important to understand the shape of the bid 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 $s_t\left(c_i;\overline{s},\tau_t\right) = 1$ for all t and increasing in c_i whenever $s_t\left(c_i;\overline{s},\tau_t\right) \in [0,1)$ for at least one t. This result is intuitive, since prime contractors who subcontract the entire project to DBE firms will have the same project cost independent of their non-DBE cost. In the data, no prime contractors subcontract the entire project to DBE firms, so the empirical application avoids this potential theoretical problem.

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

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

Proposition. *For a given task t and a given non-DBE cost draw c_i, if $s_t(c_i; 0, \tau_t) \neq s_t(c_i; \overline{s}, \tau_t)$, then $s_t(c_i; 0, \tau_t) < s_t(c_i; \overline{s}, \tau_t)$.*

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

$$\tau_t c_i = P'_t(s_{i,t}; \tau_t) + \varphi_{s_t}(\boldsymbol{s}_i; \overline{s}; \boldsymbol{\tau}).$$

Given the assumption $s_t(c_i; 0, \tau_t) \neq s_t(c_i; \overline{s}, \tau_t)$, it must be the case that $\varphi_{s_{i,t}}(\boldsymbol{s}_i; \overline{s}, \boldsymbol{\tau}) < 0$. 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 $s_t(c_i; 0, \tau_t)$ and $s_t(c_i; \overline{s}, \tau_t)$[22]: both solutions are interior solutions, one of the two solutions is an interior solution while the other is a corner solution, or both solutions occur at different corners. In either of these three cases $s_t(c_i; 0, \tau_t) < s_t(c_i; \overline{s}, \tau_t)$. □

A.4 Proof of Weakly Higher Project Costs (Corollary 1)

Corollary. *DBE subcontracting requirements weakly raise project costs.*

Proof. Suppose bidder i wins an auction with a bid of b. Without subcontracting requirements, it would choose shares, $\boldsymbol{s}(c_i; 0, \boldsymbol{\tau})$, such that

$$\boldsymbol{s}(c_i; 0, \boldsymbol{\tau}) \in \arg\max_{\boldsymbol{s}_i} \left\{ b - \sum_{t=1}^{T} (\tau_t c_i(1 - s_{i,t}) + P_t(s_{i,t}; \tau_t)) \right\},$$

or analogously,

$$\boldsymbol{s}(c_i; 0, \boldsymbol{\tau}) \in \arg\min_{\boldsymbol{s}_i} \left\{ \sum_{t=1}^{T} (\tau_t c_i(1 - s_{i,t}) + P_t(s_{i,t}; \tau_t)) \right\}.$$

Define $C(s_{i,t}; 0, \boldsymbol{\tau}) = \sum_{t=1}^{T} (\tau_t c_i(1 - s_{i,t}) + P_t(s_{i,t}; \tau_t))$ as the project cost of bidder i when there are no DBE subcontracting requirements, and consider the optimal share with subcontracting requirements, $\boldsymbol{s}(c_i; \overline{s}, \boldsymbol{\tau})$. Since $\boldsymbol{s}(c_i; 0, \boldsymbol{\tau})$ is the minimizer of $C(\cdot; 0, \boldsymbol{\tau})$, $C(\boldsymbol{s}(c_i; 0, \boldsymbol{\tau}); 0, \boldsymbol{\tau}) \leq C(\boldsymbol{s}(c_i; \overline{s}, \boldsymbol{\tau}); 0, \boldsymbol{\tau})$. Since fines are non-negative, $C(\boldsymbol{s}(c_i; \overline{s}, \boldsymbol{\tau}); 0, \boldsymbol{\tau}) \leq C(\boldsymbol{s}(c_i; \overline{s}, \boldsymbol{\tau}); 0, \boldsymbol{\tau}) + \varphi(\boldsymbol{s}(c_i; \overline{s}, \boldsymbol{\tau}); \overline{s}, \boldsymbol{\tau}) = \phi(c_i; \overline{s}, \boldsymbol{\tau})$. □

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

A.5 Proof of Weakly Lower Markups (Corollary 2)

Corollary. *DBE subcontracting requirements weakly lower markups.*

Proof. Proposition 2 implies that $s_t\left(c_i; 0, \tau_t\right) \leq s_t\left(c_i; \overline{s}, \tau_t\right)$ for all tasks, t, and non-DBE costs, c_i. Therefore, markups are weakly lower with DBE subcontracting requirements, since

$$\sum_{t=1}^{T} \tau_t \int_{c_i}^{\overline{c}} \left(1 - s_t\left(\tilde{c}; \overline{s}, \tau_t\right)\right) \left(1 - F\left(\tilde{c}\right)\right)^{N-1} d\tilde{c} \leq \sum_{t=1}^{T} \tau_t \int_{c_i}^{\overline{c}} \left(1 - s_t\left(\tilde{c}; 0, \tau_t\right)\right) \left(1 - F\left(\tilde{c}\right)\right)^{N-1} d\tilde{c}.$$

$\square$

B Microfoundations for the DBE Pricing Function

My 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 subcontractor performing work in task t will have a thrice continuously differentiable cost function C_t : $[0, 1] \rightarrow \mathbb{R}$, which maps the requested share of work into a cost for the subcontractor. I will refer to that cost function as the DBE cost function. Furthermore, I assume that $C_t', C_t'', C_t''' > 0$ so that the DBE cost function will result in an increasing and convex DBE pricing function consistent with the pricing function presented in the paper. Since the subcontracting market does not depend on its proportion of the total of any given project, I drop the τ_t notation.

Perfect Competition

Some tasks may have DBE subcontractors that behave competitively as price takers. For these tasks, DBE subcontractors 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 DBE pricing function reflects the marginal cost of the DBE subcontractors.

Monopoly

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

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

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

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

where $\epsilon = \frac{ds/s}{dP/P}$ is the price elasticity of demand in the market for that DBE's services. In words, the DBE pricing function represents the monopolist's markup over its marginal cost.[23] Note here that not all market demand functions will result in a one-to-one relationship between prices and DBE shares; a sufficient condition for this relationship to be a function is that the market demand's elasticity is constant.

C   Estimation Appendix

In order to maintain desirable properties of the model across different parameter guesses, I must restrict the model's set of possible parameter values. I include these restrictions along with details on the optimal weighting matrix and asymptotic standard errors in this appendix.

C.1   Parametric Restrictions

I restrict the parameters so 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

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[23]Observe that I implicitly assume that the monopolist firm does not strategically take the fine function into consideration when determining its prices.

second-order conditions of the DBE pricing function and the fine function for any given auction:

$$P'(s_i) = \left(\alpha_0 + \alpha_1 s_i + \alpha_2 \frac{s_i}{1 - s_i} + \alpha_3' z_w + u_w\right) \hat{x}_w + \left(\alpha_1 + \frac{\alpha_2}{(1 - s_i)^2}\right) s_i \hat{x}_w$$

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

$$P''(s_i) = 2\left(\alpha_1 + \frac{\alpha_2}{(1 - s_i)^2}\right)\hat{x}_w + \left(\frac{2\alpha_2}{(1 - s_i)^3}\right) s_i \hat{x}_w$$

$$\varphi''(s_i; \overline{s}) = \begin{cases} 2\gamma\hat{x} & \text{if } s_i < \overline{s} \\ 0 & \text{if } s_i \geq \overline{s} \end{cases}.$$

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 $s_i \in [0, 1]$. In estimation, I restrict the structural parameter values to the aforementioned range of possible values to maintain those properties across parameter guesses.

C.2 Standard Errors and Optimal Weighting Matrix

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

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

with

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

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

and

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

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Notation wise, $\hat{\theta}_{HW}$ are the structural parameters estimated from the data, θ_0 are the true structural parameters, Ω is a positive definite weighting matrix, β_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 $\Omega^\star = (V_{\beta_0})^{-1}$, yielding an asymptotic variance of $V_\theta = \left(1 + \frac{1}{H}\right)(D'\Omega^\star D)^{-1}$.

In practice, I replace the objects of the asymptotic distribution by consistent estimators. Specifically, I use the following consistent estimators in place of their asymptotic counterparts:

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

and

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

In constructing $\hat{V}_{\beta_{HW}(\hat{\theta}_{HW})}$, the estimator for V_{β_0}, I use a parametric bootstrap procedure.

D Estimated Pricing and Fine Functions
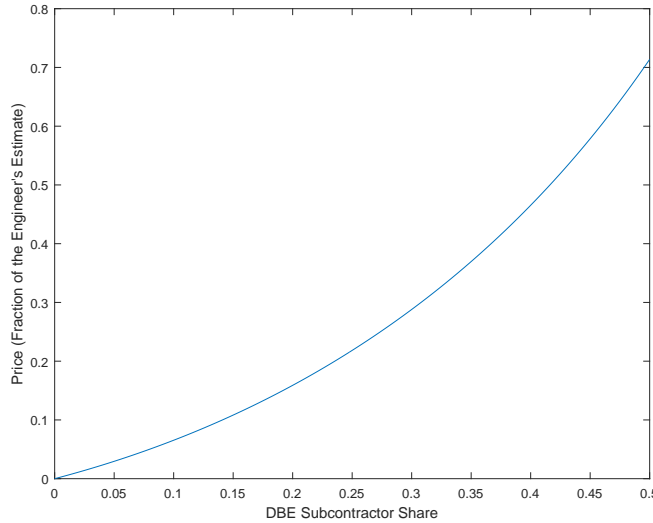
Figure 5: The DBE Pricing Function as a Fraction of the Engineer's Estimate

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 (σ_u) when there is an established DBE subcontracting requirement of 7.5 percent.
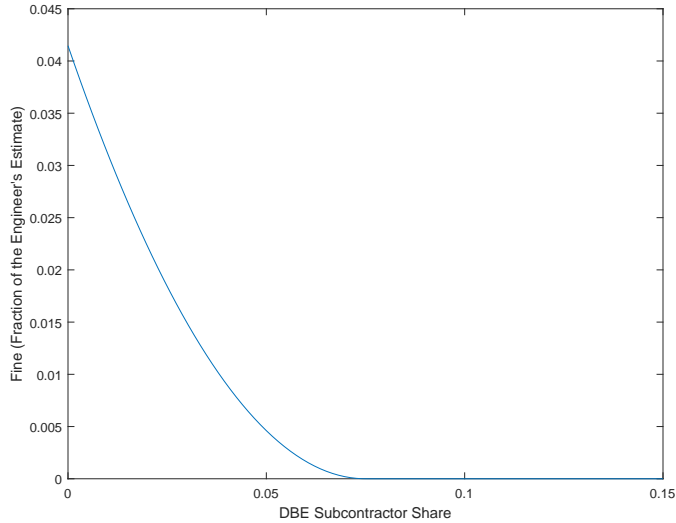
Figure 6: Fine Function as a Fraction of the Engineer's Estimate

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   Relative Cost of DBE Subcontractors

A common criticism of requiring the use of DBE subcontractors is that they are more costly. To assess whether this criticism is supported by the data, I generate a measure of the cost of using DBE subcontractors relative to non-DBE costs 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, I use the modal project characteristics for each type of project in the DBE-eligible data to calculate these measures.

I construct the relative cost measure as the ratio of a prime contractor's DBE cost of subcontracting s_i percent of a project $(P(s_i))$ to that contractor's non-DBE cost of completing s_i percent of a project $(c_i s_i)$. I will now refer to this measure as the DBE cost ratio. When the DBE cost ratio is one, it is just as costly for a prime contractor to use DBE subcontractors as their own resources, and when the DBE cost ratio is greater than one, DBE subcontractors are relatively more expensive. Given that the price of DBE subcontractors also depends on the realization of the DBE pricing shock, I plot this ratio for the 25th, 50th and 75th percentiles of the shock's distribution.

Figure 7 illustrates how the DBE cost ratio changes across different projects and price shock realizations. For both types of projects, DBE subcontractors are likely to be relatively more costly since the DBE cost ratio is greater than one for most draws of the pricing shock. There are regions of the pricing shock's distribution
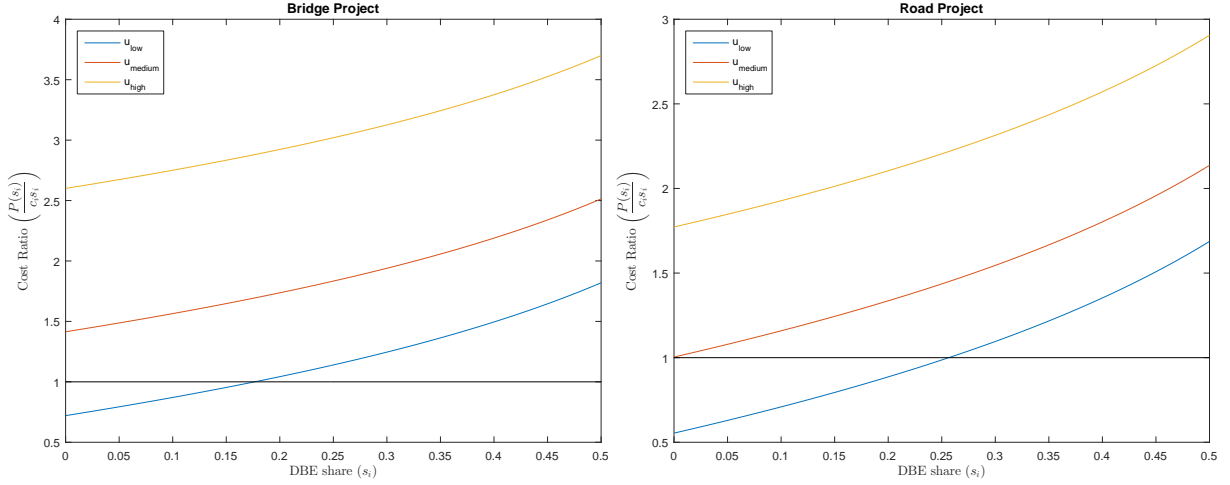
Figure 7: DBE Cost Ratios

Note: DBE cost ratios for the modal bridge and road construction projects. The vertical axis has the DBE 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 25th percentile, "medium" corresponds to the 50th percentile, and high corresponds to the 75th percentile of the shock's distribution.

where DBE subcontractors are less costly, which suggests that DBE utilization is sensitive to the realization of the shock.

F   Subsidy and Quota Simulations

In this section, I repeat the numerical simulations with quotas and subsidies. I maintain the environment and functional form assumptions from section 4; for completeness, I list those assumptions below:

- $N = 2$

- $T = 2$

- $c_i \sim U[0, 1]$, where $U[\cdot, \cdot]$ denotes the uniform distribution.

- $\tau_1 = \tau_2 = 0.5$

- $P_t(s_{i,t}; \tau_t) = \frac{\xi_t \tau_t s_{i,t}^2}{2}$

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

- $\xi_1 = 1$, $\xi_2 = 2$, $\lambda = 3$

45

For simplicity, I assume that the quota and subsidy are the same across all tasks, and I set the quota and subsidy to 30% on each task to match the simulations with subcontracting requirements.

Figure 8 shows the DBE subcontracting functions when there is a quota (the top two panels) and subsidy (the bottom two panels) and compares them to the subcontracting functions when there is no policy. For quotas, the DBE subcontracting functions are flat at the quota share if prime contractors would have subcontracted below the quota and match the non-quota DBE subcontracting functions otherwise. This shape comes from the constraint that prime contractors must meet the quota. For subsides, the DBE subcontracting function is a rotation of the unsubsidized DBE subcontracting function. This shape is intuitive: prime contractors with lower non-DBE costs are less likely to use DBE subcontractors when they are subsidized. An important difference between subsidies and subcontracting requirements is that subsidies distort the more efficient contractors' subcontracting decisions less, while subcontracting requirements distort the less efficient contractors' subcontracting decisions more.

Next, I simulate the bid functions, which are displayed in figure 9. The bid function under the quota is similar to the bid function under subcontracting requirements, but the bids are relatively higher for prime contractors with lower non-DBE costs. This property comes from prime contractors losing the option to pay a fine instead of using DBE subcontractors, which leads to higher project costs.

The bid function under the subsidy is visibly lower than the bid function under subcontracting requirements. This effect is intensified for prime contractors with high non-DBE costs. Intuitively, DBE subcontractors are cheaper with the subsidy, which leads to lower project costs. Since prime contractors use more DBE subcontractors with a subsidy, their markups are also lower, leading to lower equilibrium bids.
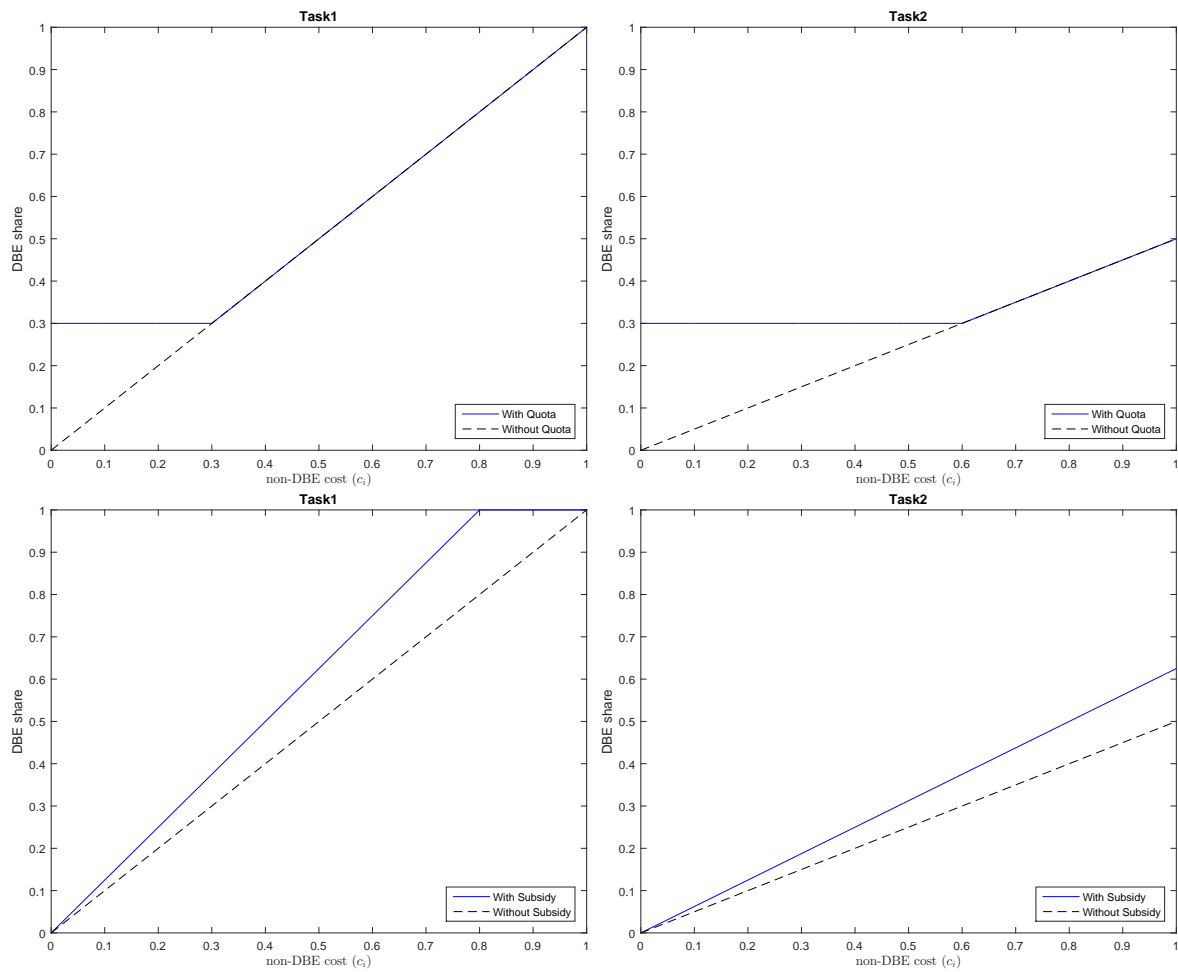
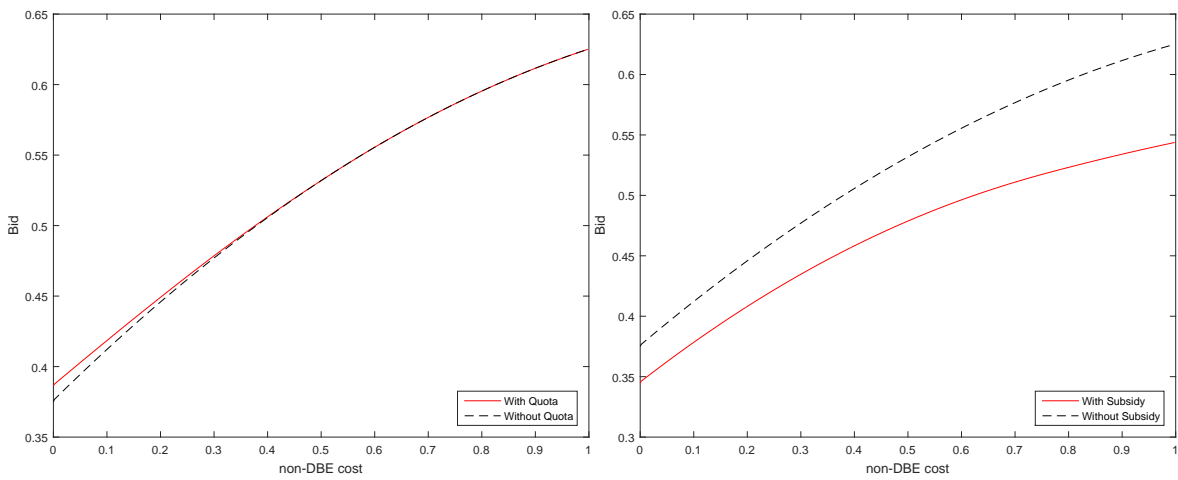Figure 8: DBE Share Functions with Quotas and Subsidies

Figure 9: Bid Functions with Quotas and Subsidies

My last simulation shows how procurement costs change with the subsidy; this simulation is contained in figure 10. Interestingly, procurement costs for prime contractors with low non-DBE costs are lower with the subsidy, and the reverse is true for prime contractors with high non-DBE costs. The idea behind this result is that prime contractors with low non-DBE costs are less likely to use the subsidy but still bid lower than the unsubsidized case, leading to lower procurement costs. Also observe that there is a kink in the procurement cost figure because prime contractors reach the right boundary condition on the first task with the subsidy.
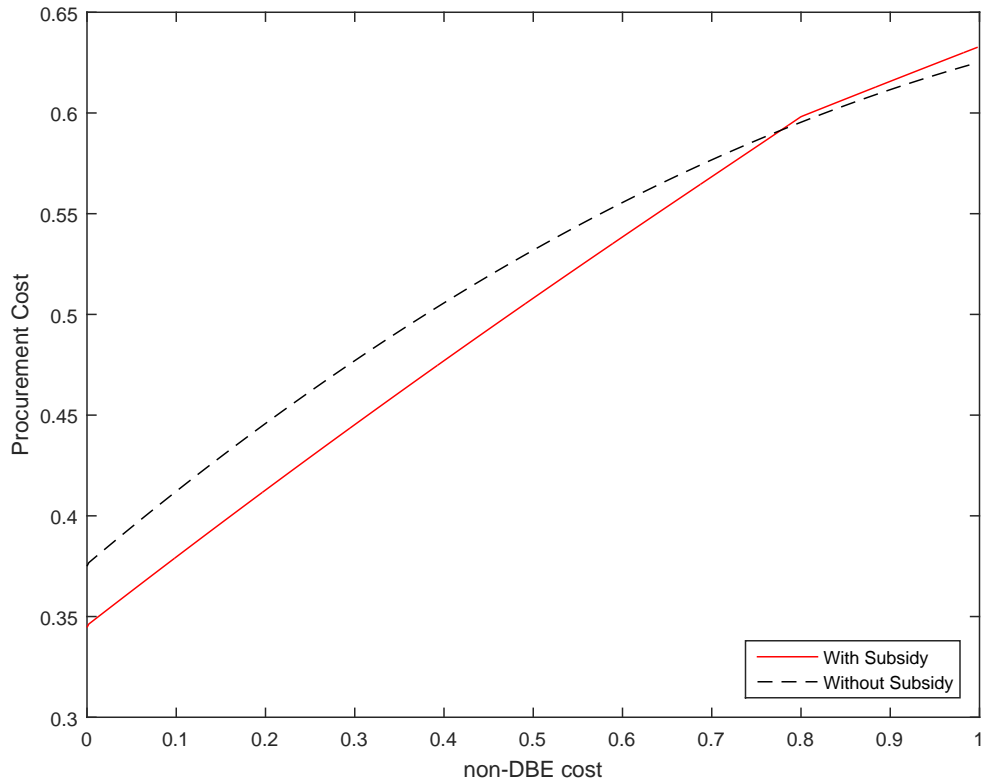

Figure 10: Procurement Cost with Subsidies

G   Invitation for Bids

I gather the majority of the observable variables from the invitation for bids document that the NMDOT publishes to advertise its available construction projects. Figure 11 contains an excerpt from the NMDOT's January 22nd, 2010 advertisement. The first paragraph specifies the county, which is later aggregated up to administrative district, and length. The second paragraph lists the project's components. In my empirical analysis, I take the component in uppercase letters (in this case, roadway rehabilitation) as the main project, and I take the following components as the 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 11: IFB Example

H   Additional Regressions and Graphs

Number of Projects by DBE Goal
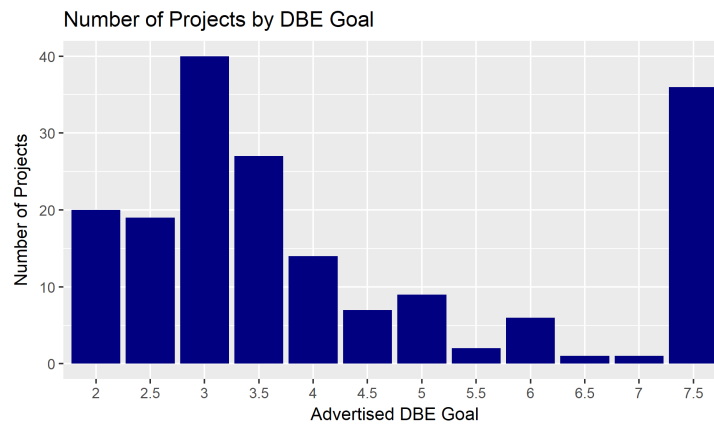
Note: This figure shows the distribution of non-zero DBE subcontracting requirements.

Difference between DBE Goal and Actual DBE Share
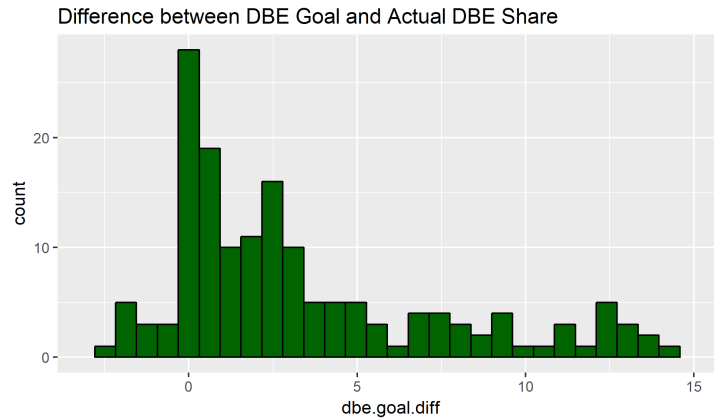
Note: This figure shows the percentage difference between the share of DBE subcontractors actually used on a given project and the DBE subcontracting requirement conditional on the project having a subcontracting requirement. Although there is some bunching at 0 percent, there is a non-trivial mass of 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 12 and 13 motivate the main modeling assumptions of the paper. Table 12 contains a regression specification very similar to the first three columns of tables 2 and 3, but I include 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) as an additional observable. This regression motivates the absence of capacity constraints in my 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 13 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 12: Capacity Regressions

	Dependent variable:	
	log(Winning Bid)	DBE Share (%)
	(1)	(2)
log(Engineer's Estimate)	0.927***	−0.352
	(0.017)	(0.624)
DBE Req (%)	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)
Number of Licenses Required	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)
Federal Highway	−0.034	−0.240
	(0.022)	(0.690)
Urban	−0.018	1.899*
	(0.034)	(0.970)
Observations	389	389
Adjusted R^2	0.985	0.227

Table 13: Entry Regressions

	Dependent variable:	
	Bidders/Planholders	Planholders
	(1)	(2)
log(Engineer's Estimate)	0.008	1.392***
	(0.008)	(0.353)
DBE Req (%)	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)
Number of Licenses Required	−0.022**	1.194***
	(0.009)	(0.457)
log(Working Days)	−0.018*	1.554***
	(0.011)	(0.408)
Federal Highway	0.001	−0.543
	(0.011)	(0.429)
Urban	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.