Subcontracting Requirements and the Cost of Government Procurement[*]

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Abstract

Government procurement contracts are frequently subject to policies that specify a subcontracting requirement for the utilization of historically disadvantaged firms. I study how such subcontracting policies affect procurement auctions using data from New Mexico's Disadvantaged Business Enterprise Program. Theoretically, subcontracting requirements reduce prime contractors' private information on their costs by requiring them to select their subcontractors from a common pool of disadvantaged firms. This feature mitigates cost increases from using more costly subcontractors by causing prime contractors to strategically lower their markups. My estimated model reveals that New Mexico's past subcontracting requirements led to minor increases in procurement costs.

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[*] I thank Marc Rysman, Mike Abito, Katja Seim, Hanming Fang, Aviv Nevo, Jorge Balat, various seminar participants, and two anonymous referees for their guidance and comments. I gratefully acknowledge David Coriz of the New Mexico Department of Transportation for providing parts of the data and funding from the NSF and AEA Summer Mentoring Program.

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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 article, I study how these subcontracting policies affect procurement outcomes.

A key feature of subcontracting requirements is that they require prime contractors—which are the firms responsible for bidding on and finishing projects, potentially through employing subcontractors—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 the model, prime contractors can complete projects 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 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, therefore, reduce their markups in their bids. The main finding in my article 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) to evaluate their Disadvantaged Business Enterprise (DBE) Program. Although I focus on this particular program in New Mexico, my theoretical and empirical framework applies to many other environments, including procurement with small business and veteran subcontracting requirements. As is true of many other states in the US, New Mexico's DBE program

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

[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.

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 13.8 percent increase in the amount of money awarded to DBE subcontractors yet increased procurement costs by only 0.2 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, whereas subsidies are best for governments aiming to reduce procurement costs.

My article fits into the literature on subcontracting and how it affects firms and auction outcomes. Jeziorski and Krasnokutskaya (2016) study subcontracting in a dynamic procurement auction, and their model is closely related to the model in my article. The main difference between their model and mine is that I study how different subcontracting policies affect bidding and DBE subcontracting in a static setting. These policies are frequently used in government procurement and can lead to a variety of different procurement outcomes. Additionally, their empirical application relies on calibrated parameters, whereas my empirical model allows me to identify and estimate all of its primitives. Other studies of subcontracting include Marion (2015), 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 (2015), who use Italian data to determine the effects of subcontracting by choice as opposed to subcontracting by law, and De Silva et al. (2017), who study how subcontracting affects the survival of firms competing for road construction projects.

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

My article'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, 2017) 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. (2020), 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 than 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 studies 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 (2019), 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 this article 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, and section 6 contains my descriptive analysis and estimation results. Section 7 presents my counterfactual 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.

Letting

The NMDOT advertises new construction projects four weeks before 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 to complete each project. The contract proposals contain a plan for completing the required work, including 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 before 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 selection process as a first-price, sealed-bid procurement auction. The NMDOT also publishes an engineer-estimated cost of the project on the date of bid opening, which I refer to as the project's engineer's estimate. This estimate corresponds to the amount the NMDOT considers fair and reasonable for the required work and is typically based on market prices and historical bid data. Additionally, engineer's estimates are generally formed before the NMDOT sets requirements and are empirically uncorrelated with the requirements, making requirement-based adjustments unlikely. In line with the procurement auction literature, I use the engineer's estimate as a proxy for project size.

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[3] See the NMDOT's Consultant Services Procedures Manual available at http://dot.state.nm.us/en/Program_Management.html.

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, whereas 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 considers several different factors. In particular, the NMDOT bases its 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 consider only projects with both subcontracting opportunities and estimated costs of more than $\$300,000$ eligible for DBE subcontracting requirements. Because those projects are the only ones eligible for subcontracting requirements, my empirical and counterfactual analyses focus on those larger projects.

Once established, the NMDOT gives prime contractors some incentives to meet a project's subcontracting requirement. Although the requirement is not a binding quota, contractors who fall short of the requirement

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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.

incur additional costs in the form of showing a "good faith effort" to use DBE subcontractors to 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 contractors who miss the subcontracting requirement. Note that bid rejection for non-compliant firms is irregular. The DBE Program rules at the time had no provisions for rejecting non-compliant bids, and in my conversations with him, the NMDOT's DBE liaison could not find a case of bid rejection because firms that missed the requirement were able to show good faith efforts.

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 the cost of using DBE subcontractors across firms.

In the model, I represent the cost of using DBE subcontractors with a function common to all prime contractors. As is typical in many other states, New Mexico does not keep data on the subcontractors used by bidders who do not win, so I cannot test whether DBE subcontractor utilization is common within projects directly. Across projects, however, winning prime contractors tend to use a limited set of DBEs. On traffic sign installation work, which is commonly subcontracted to DBEs, the three most utilized firms completed 88.9 percent of all DBE-subcontracted work. There were a total of 43 different winning primes. On fencing work, which also tends to use DBE subcontractors, the three most utilized firms completed 92.2 percent of all work issued to DBE subcontractors. There were a total of 32 different winning primes, and other types of work have comparable patterns. In states with DBE systems similar to New Mexico's but keep public records of DBE commitments on projects with subcontracting requirements, bidders rarely use different firms to satisfy the DBE subcontracting requirement. For example, in a sample of lettings from Iowa, 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 information allows me to 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

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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.

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 (2016) but adds and investigates a policy that encourages the use of DBE subcontractors.[6]

In the model, prime contractors decide how much work to give DBE subcontractors and how much to bid on each project. 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. Although analyzed within the context of DBE requirements, note that the results from this section are not unique to DBEs and can be applied to any setting where prime contractors are required to use a common pool of approved subcontractors—even when there are no societal goals to improve disadvantaged business participation.

Environment and Objective Function

Formally, N risk-neutral bidders compete against each other for the right 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 before submitting bids.

Observe that some form of symmetry, which in my model amounts to a common distribution for non-DBE costs, is a standard simplifying assumption in the auction literature. The alternative would be to have bidders draw their non-DBE costs from asymmetric distributions, which would require numerical approximations to solve. Given that my estimation procedure relies on solving each auction in the data many times and that

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[6] Jeziorski and Krasnokutskaya (2016) also include capacity dynamics and entry in their model. In the web Appendix, I provide descriptive evidence suggesting that DBE requirements are uncorrelated with entry and that capacity is uncorrelated with bidding and DBE subcontracting. Thus, I abstract away from these two outcomes.

adding asymmetries would substantially complicate the model's solution, I maintain the standard symmetry assumption in this article.

In addition to the usual 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, bidders choose a share of the project, $s_i \in [0,1]$, to subcontract to DBE firms, which reduces their portion of the cost of completing the project from c_i to $c_i\,(1-s_i)$. I model a bidder's cost of using DBE subcontractors with an increasing, convex, and twice continuously differentiable function $P:\,[0,1] \to \mathbb{R}_+$, which I refer to as the DBE pricing function. This function represents the prices received by prime contractors from DBE subcontractors through the quote-solicitation process and is known to all bidders; maps the share of the project using DBE subcontractors into a cost of using DBE subcontractors; and can be everywhere below, everywhere above, or cross non-DBE costs.[7] The cost of using a DBE subcontracting share of s_i is then $P\,(s_i)$, and I will refer to this cost as a bidder's DBE cost. Note that this function maps shares into costs, so it differs from the standard inverse supply function.

A limitation of placing this type of structure on the DBE subcontracting market is that it assumes away any 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.[8] This assumption also precludes the possibility that contractors located closer to DBE firms may have an advantage in the hiring process, although the common practice of soliciting DBE quotes over the internet suggests that locational sorting in relationships is limited. Instead, I assume that each bidder has access to the same DBE subcontracting technology.

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 before any bidding or DBE subcontracting decisions. A choice of $\overline{s}=0$ in this environment is analogous to not having a subcontracting requirement.

I assume that the NMDOT enforces its subcontracting requirements through fines. These fines represent any additional costs to bidders who miss the subcontracting requirement, including any actual fines and

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[7] Ideally, I would model the DBE subcontracting market separately, and the price would be an endogenous outcome of that market. However, because the data contain information on the prices listed by DBE subcontractors only, the extent to which I can model the subcontracting market is limited.

[8] In a recent study, Rosa (2020) uses simulations to investigate subcontracting quotas when there is dynamic relationship formation, finding that relationships make bidders asymmetric and that affirmative action quotas expand this asymmetry.

any additional work required to show the NMDOT good faith effort to use DBE subcontractors. Formally, subcontracting requirements alters a bidder's optimal choice of DBE subcontracting and bidding through a fine function $\varphi : [0,1] \rightarrow \mathbb{R}_+$, which is common knowledge and maps a bidder's choice of DBE subcontracting given the DBE subcontracting requirement into a non-negative value. 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

$$\max_{\{b_i, s_i\}} \left(b_i - c_i \left(1 - s_i\right) - P\left(s_i\right) - \varphi\left(s_i; \overline{s}\right)\right) \times \Pr\left(b_i < b_j \forall j \in N \setminus \{i\}\right). \tag{1}$$

A strategy in this environment is a 2-tuple that consists of a bid function $b_i : [\underline{c}, \overline{c}] \rightarrow \mathbb{R}_+$ and a DBE subcontracting share function $s_i : [\underline{c}, \overline{c}] \rightarrow [0,1]$, which, for all levels of $\overline{s}$, 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 few interesting changes to the competitive bidding environment. Perhaps the most salient of these changes is that the DBE subcontracting market allows all bidders to substitute between completing projects 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 part 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 because all bidders have equal access to DBE subcontracting.

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 $s\left(c_i; \overline{s}\right)$. My analysis of the second-order conditions is contained in the appendix; see Appendix A. For an interior choice of $s\left(c_i; \overline{s}\right)$, the first-order conditions require that

$$c_i = P'\left(s_i\right) + \varphi'\left(s_i; \overline{s}\right). \tag{2}$$

For bidders whose optimal choice is to use no DBE subcontractors, the following condition must hold:

$$c_i < P'(0) + \varphi'(0; \overline{s}). \tag{3}$$

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

$$c_i > P'(1) + \varphi'(1; \overline{s}). \tag{4}$$

Because the fine is continuously differentiable, there is no possibility that prime contractors with different non-DBE costs will bunch at the requirement.

There are a few key properties of optimal DBE subcontracting. Similar to Jeziorski and Krasnokutskaya (2016), the optimal DBE subcontracting decision does not depend on the probability of winning the auction. Intuitively, subcontracting affects a bidder's objective function through the payoff conditional on winning only and does not directly affect the probability of winning. Therefore, bidders 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; then, bidders determine how much to bid given their optimal choice of s_i.

Before moving into the bidding strategies, note the effect of DBE subcontracting requirements on DBE subcontracting decisions. With an interior choice of $s(c_i; \overline{s})$, assigning a positive DBE subcontracting requirement on a project affects the DBE subcontractor choice through the fine. Bidders are more likely to change their subcontracting behavior if φ changes rapidly in s_i, implying that policies that impose larger marginal fines for missing the DBE subcontracting requirement are more effective in changing equilibrium DBE subcontracting shares.

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 non-DBE cost, its DBE costs, and any fines.[9] Formally, I define a bidder's project cost as

$$\phi\left(c_i;\overline{s}\right)=c_i\left(1-s\left(c_i;\overline{s}\right)\right)+P\left(s\left(c_i;\overline{s}\right)\right)+\varphi\left(s\left(c_i;\overline{s}\right);\overline{s}\right).$$

Substituting ϕ into equation (1) and removing the optimization over 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).[10] 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

$$\phi'\left(c_i;\overline{s}\right)=\left(1-s\left(c_i;\overline{s}\right)\right)\geq 0, \tag{5}$$

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 $s\left(c_i;\overline{s}\right)\in[0,1)$ and flat whenever $s\left(c_i;\overline{s}\right)=1$. 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 $s\left(c_i;\overline{s}\right)=1$.

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. Proposition 1 presents the bid function expression, with the details of its derivation contained in Appendix A.

Proposition 1. *The optimal bid function is*

$$\begin{aligned} b\left(c_i;\overline{s}\right) &= \underbrace{\frac{\int_{c_i}^{\overline{c}}\left(1-s\left(\tilde{c};\overline{s}\right)\right)\left(1-F\left(\tilde{c}\right)\right)^{N-1}d\tilde{c}}{\left(1-F\left(c_i\right)\right)^{N-1}}}_{\text{Markup}} \\ &+ \underbrace{c_i\left(1-s\left(c_i;\overline{s}\right)\right)+P\left(s\left(c_i;\overline{s}\right)\right)+\varphi\left(s\left(c_i;\overline{s}\right);\overline{s}\right)}_{\text{Project Cost}}. \end{aligned} \tag{6}$$

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[9] 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.

[10] Observe that $\overline{\phi}=P(1)+\varphi\left(1;\overline{s}\right)$ is the project cost of a bidder that subcontracts the entire project to DBE firms. I derive this expression from the previous result that the optimal DBE subcontracting share is increasing in c_i.

There are a few 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 DBE subcontracting 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.

Note that 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.[12]

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 non-DBE cost draw* c_i*, if* $s\left(c_i; 0\right) \neq s\left(c_i; \overline{s}\right)$*, then* $s\left(c_i; 0\right) < s\left(c_i; \overline{s}\right)$*.*

Proposition 2 says that when 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 when DBE subcontractors are 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 share 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

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[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.

[12] In the data, only 4.6 percent of all auctions have one bidder.

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 reduces the bidder's markup, and 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. Because bidders can markup only 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 $[0, 1]$. For simplicity, I assume that the pricing functions and the fine function are quadratic and that prime contractors are fined only if their total share of work going to DBE subcontractors is below the subcontracting requirement:

$$\begin{aligned} P(s_i) &= \frac{\xi s_i^2}{2} \\ \varphi(s_i; \overline{s}) &= \begin{cases} \frac{\lambda (s_i - \overline{s})^2}{2} & \text{if } s_i < \overline{s} \\ 0 & \text{if } s_i \geq \overline{s} \end{cases}, \end{aligned}$$

where ξ and λ are coefficients that control the steepness of the pricing and fine functions, respectively. To keep this example simple, I set $\xi = 2$; I set the fine coefficient, λ, to 3 so that the fine is sufficiently steep to visibly change subcontracting behavior. I use a subcontracting requirement of 30 percent ($\overline{s} = 0.3$) when it applies.

I begin my analysis by first solving for the optimal DBE subcontracting share 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 1 contains plots of these functions.

Subcontracting requirements lead to several 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 costs and leave shares unchanged for prime contractors with higher non-DBE costs, which is consistent with Proposition 2. Intuitively, prime contractors with lower non-DBE costs find it more profitable to use 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 above the requirement, the fine is no longer effective, so there is no change in DBE subcontracting behavior.

Given the optimal DBE subcontracting solutions, 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 and fine functions. To illustrate the markup intuition, I start by separating the bid functions into their markup and project cost components.

Figure 2 contains my results, with markups shown in the left panel and project costs in the right panel. Because requirements distort DBE subcontracting decisions away from their cost-minimizing levels at low non-DBE costs, affected prime contractors have higher project costs when there are requirements. In contrast, the higher subcontracting induced by the requirements also leads to lower markups because prime contractors use more of the common DBE resource. Markups and project costs are unaffected for higher non-DBE cost firms because requirements do not change how they subcontract.

Figure 3 combines these two components into bid functions. 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 have low non-DBE costs. For this range of non-DBE costs, 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 the 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 results in minimal changes optimal bidding, implying small changes in procurement costs.

5 Empirical Model and Estimation

Although the theoretical model can account for several different ways subcontracting requirements can affect bidding and DBE subcontracting, it cannot be applied to the New Mexico data without additional assumptions on the model's primitives. In this section, I outline those assumptions and describe the estimation procedure. I end this section by discussing the sources of variation in the data that identify the empirical model's parameters.

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 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 particular area. 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 $DBE\,req = \overline{s}_w \times 100$. This assumption allows for the possibility that the NMDOT assigns subcontracting requirements on projects where DBEs are less costly.

Note that my unobserved characteristic differs from the more standard notion of unobserved heterogeneity. In those models, identification is based on a deconvolution strategy inspired by Li and Vuong (1998) and requires one to observe the joint distribution of at least two bids within an auction. Because my limited information on DBE subcontracting requires that I estimate my model with the winning bids only, a similar approach is not possible in my setting. In Section 5, I discuss identification further.

For the non-DBE cost distribution, I parameterize it to have a bounded support, which is consistent with the theoretical assumptions. In particular, I assume that non-DBE costs follow a truncated log-normal distribution:

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

where ψ is a vector of structural parameters that shift the non-DBE cost distribution and $\bar{c}_w$ is the project-specific upper bound on the non-DBE cost distribution. Given that c_i is log-normal, its support is bounded below by 0. I use the variable $\bar{c}_w$ to get the upper limit of integration when solving for the equilibrium bids in equation (6), and I construct $\bar{c}_w$ 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 engineer's estimate, and suppose k is the maximum of the ratio of all bids relative to the engineer's estimate $\left(k = \max\left\{\frac{b_{iw}}{\hat{x}_w}\right\}\right)$; then, my upper bound is given by $\bar{c}_w = k\hat{x}_w$. Observe that my construction of the upper bound is a parametric assumption that I cannot directly test with the data. In practice, I find that my truncation parameter is high enough so that my results are not sensitive to its value.[13]

I use parametric functional forms for the pricing and fine functions similar to the ones used by Jeziorski and Krasnokutskaya (2016). In particular, I assume that the DBE pricing function and fine function take the following functional forms:

$$P(s_i) = \left(\alpha_0 + \alpha_1 s_i + \alpha_2 \frac{s_i}{1-s_i} + \alpha_3' \boldsymbol{z}_w + u_w\right) s_i \hat{x}_w \tag{7}$$

$$\varphi(s_i; \bar{s}_w) = \begin{cases} \gamma\left(s_i - \bar{s}_w\right)^2 \hat{x}_w & \text{if } s_i < \bar{s}_w \\ 0, & \text{if } s_i \geq \bar{s}_w \end{cases}. \tag{8}$$

The hyperbolic term in equation (7) prevents firms from subcontracting entire projects to DBE subcontractors. In practice, there are often limitations on the amount of work that a prime can subcontract, and I use this functional form to approximate those limitations. The scaling by $\hat{x}_w$ in P and φ ensures that the problem scales properly because 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 (8) 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 B.

A potential issue with my specification is that the unobserved characteristic, u_w, may be correlated

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[13] In practice, $k = 3.94$.

with non-DBE costs, as would be the case if unobserved conditions in the DBE subcontracting market also affect the general subcontracting market. In that scenario, both forms of subcontracting would be unobservably cheaper (or more expensive) than the prime contractor simultaneously, so one would expect to see a positive correlation between DBE and non-DBE subcontracting shares conditional on observables. However, regressions of non-DBE subcontracting shares on DBE subcontracting shares suggest that this correlation is negative and economically insignificant. Regressions of non-DBE subcontracting shares on the requirement produce correlations that are small, negative, and statistically indistinguishable from zero, which is likely because the agency that sets these requirements in New Mexico does not consider subcontracting conditions beyond those that pertain to DBE subcontractors. Thus, although my estimates are limited by it, the extent to which the unobserved characteristic is correlated with non-DBE costs is likely minimal.

Also, observe that my non-DBE cost parameterization does not account for factors that may be known to bidders but are unobserved to the econometrician. In the auction literature, these factors are known as unobserved heterogeneity and were first introduced by Krasnokutskaya (2011). The prevalence of unobserved heterogeneity is likely limited by the engineer's estimate, though, as it explains a substantial part of the variation in bids.

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. This estimator is generally less computationally demanding than maximum-likelihood-based estimators and matches the parameters from an auxiliary model, which is a reduced-form model used to approximate the data-generating process, 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. Because bids are increasing in non-DBE costs, I 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 (2). To account for corner solutions, I take the maximum of 0 and the DBE shares obtained from solving the first-order

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[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.

conditions for s_i; the other corner solution is ruled out because the parameterization of $P(s_i)$ would imply infinite DBE costs when $s_i = 1$. With the shares calculated, I solve for the equilibrium winning bids using equation (6). Because the optimal DBE share function appears in the integral of equation (6), this step requires an approximation of the DBE share function. I use a spline approximation of this function, which I obtain by fitting a Hermite spline through 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

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

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, ϵ_{bw} is the error term on the winning bid regression, and $\overline{s}_w$ is the subcontracting requirement in auction w.

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 B.

Identification

I conclude this section with a heuristic discussion of the data variation that pins down 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).

Identification requires that unique structural parameter values generate the data. In the data, I observe projects without subcontracting requirements where prime contractors use no DBE subcontractors. The bids on these projects allow me to pin down the non-DBE cost distribution parameters because 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 pin down 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 requirement. Given the non-DBE cost distribution parameters, the variation in DBE shares on these projects correspond to changes in the DBE pricing function. I observe additional variation in DBE subcontracting between these two types of projects. This variation allows me to pin down the σ_{u1} parameter, which is the parameter that accounts for the possibility that the NMDOT assigns subcontracting requirements when they are less costly. Intuitively, 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 can pin down γ from the bids and DBE shares of prime contractors who miss the DBE subcontracting requirement. The idea here is that fines directly affect bids and subcontracting when a prime contractor fails to reach a given requirement. Hence, the model attributes differences in bidding and subcontracting between prime contractors who meet and do not meet the requirement to γ. Additionally, notice that winning bids are indirectly linked to the fine function through the markup term because bidders need to integrate over DBE shares that would be affected by the fine. This indirect link also helps to pin down the fine.

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.

Data Description and Variables

The data contain federally funded highway construction contracts issued by the NMDOT from 2008 until 2014 for the maintenance and construction of transportation systems. To be consistent with the model, I do not include contracts won by DBE prime contractors.[15] Furthermore, I consider projects that are eligible for requirements only, which are projects estimated to cost more than $\$300,000$ to complete.

I construct the subcontracting portion of the data from administrative records from New Mexico's SHARE system. The SHARE data are part of New Mexico's state-wide accounting system and track all of the transactions between the NMDOT and the contractors who are ultimately awarded projects using federal aid. These data contain 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 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 also include the advertised DBE subcontracting requirement, which ranges from 2.0 to 7.5 percent when positive and is plotted in Figure 4. I gather these data from publicly available NMDOT bidding records, including 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

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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 because the prime contractor must perform most of the work.

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 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 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.

Summary Statistics

Table 1 presents the summary statistics from the entire sample of NMDOT highway construction contracts. I divide projects into three categories: projects with subcontracting requirements, projects without subcontracting requirements, and the whole sample of projects.

Table 1 indicates a few differences across projects with and without subcontracting requirements. On average, projects with subcontracting requirements have 2.4 more subprojects and are estimated to cost $1.4 million more than projects without subcontracting requirements. Also, projects with subcontracting requirements allocate 4.9 percentage points more to DBE subcontractors relative to projects without subcontracting requirements. Despite these differences, projects with subcontracting requirements tend to attract a similar number of bidders as 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.

Descriptive Regressions

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, as it shows the correlation between the winning

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[16] See the web Appendix for an example of subprojects.

bids and the DBE subcontracting requirement. Column (1) 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, and 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.

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. These results suggest that DBE subcontracting requirements are not associated with the ultimate cost of procurement and are 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 three 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 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.[17]

Note that this analysis is descriptive; these coefficients will be biased if there are unobservable factors that affect bidding, DBE subcontracting, and decisions of whether to include DBE subcontracting requirements on a particular project. Although the control variables account for many of those factors, there would ideally be some randomness or exogenous characteristics otherwise excluded from the model that determine the requirement—although the roundness of the requirement may suggest some arbitrariness. In my empirical model, I allow for an explicit correlation between unobserved factors influencing the requirement and the cost of using DBE subcontractors.

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[17] 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. Because I do not observe shares for the losing bidders, I am unable to test this property directly.

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. Increasing the share of work given to DBE subcontractors scales markups down. Because markups are relatively smaller when there is more DBE subcontracting, the reduction in bids due to an increased number of competing bidders should be attenuated by the amount of work assigned to DBE subcontractors. In a regression analysis relating bids to project characteristics, this attenuation effect would appear in a 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 that analysis by regressing log-winning bids on project-level covariates, with an additional control for the DBE share and an interaction term between the DBE share and the number of bidders. The regression specifications follow the same format as 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 in Table 4. Consistent with the model, there is a positive and statistically significant coefficient on the interaction term across all regression specifications. Taken together with the negative and statistically significant coefficient on the number of bidders, these regressions suggest that DBE utilization may work to reduce markups.[18]

Although I do not account for entry in these regressions or the rest of my analysis, observe that my results can be interpreted within a particular class of entry models commonly used in the literature. Namely, my results correspond to the bidding stage in models where bidders base their entry decisions on a bid preparation cost independent of their project cost and observe the number of bidders before bidding (see Krasnokutskaya and Seim (2011), for example). Because there can be no selection on project costs in the entry phase, the bidding stage in that model is the same as mine conditional on the number of entrants.

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

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[18] I also find a negative coefficient on the DBE share, but its interpretation is complicated by equilibrium subcontracting behavior. Specifically, one cannot hold all else equal when DBE shares change, as a change in DBE shares requires a change in either DBE or non-DBE costs in equilibrium.

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.

Structural Parameter Estimates

Next, I turn to the parameter estimates from the empirical model. I assume that the distribution of log-non-DBE costs is 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 (7), with the distribution of the unobserved price shock allowed to depend on the DBE subcontracting requirement and controls for the number of subprojects and whether the project is located in a rural area. The parameters of the fine function follow equation (8).

I present the results for the non-DBE cost distribution parameter estimates in Table 5. A firm's non-DBE cost is affected by several observable factors. In particular, I find that the engineer's estimate heavily influences non-DBE costs; a one percent increase in the engineer's estimate corresponds to a 0.94 percent non-DBE cost increase, and this coefficient is statistically significant. Although the engineer's estimate drives much of a firm's non-DBE costs, 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 9.5 percent to increasing non-DBE costs by 16.8 percent relative to a project located in District 1, which encompasses the City of Deming and its surrounding area. The effect of the type of work requested on non-DBE costs ranges from decreasing non-DBE costs by 14.2 percent to increasing non-DBE costs by 35.9 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—choosing a DBE subcontracting share of 1 percent requires a payment of 1.0 percent of the project's engineer's estimate to DBE subcontractors on rural projects. Although it is noisy, the fine function parameter implies that the fine associated with missing the DBE subcontracting requirement by five percent is about 2.3 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 $\$127,000$.

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. Table 7 contains the moments of these outcomes tabulated by whether there is a requirement; the shares are in percentages, and the winning bids are in millions.

The model's predicted moments match these data moments reasonably well. The model's average DBE subcontractor shares are within 0.25 percentage points of the true average DBE subcontractor shares, and the model's average winning bids are within $\$80,000$ of the average winning bids in the data. One exception is the predicted standard deviation for the DBE shares absent a requirement, which are more disperse than the actual DBE shares.

7 Counterfactual Analysis

I now use the model's parameter estimates to predict counterfactual bidding and DBE subcontracting decisions under various 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 subsidy policies and compare their outcomes with the outcomes obtained with subcontracting requirements. To be consistent with the projects that New Mexico sees fit for government intervention, I use projects with positive DBE subcontracting requirements in my analysis.

A limitation of my counterfactual study is that it does not account for entry. Given that prime contractors might be less likely to bid on contracts with more stringent DBE subcontracting policies and that a smaller number of bidders leads to higher markups, entry has the potential to bias my findings. In the data, I find that DBE requirements are uncorrelated with the number of planholders and the proportion of planholders that eventually become bidders, which suggests that entry may not be a first-order concern in New Mexico for the modest counterfactual policies I consider here. Nevertheless, any counterfactual estimates related to a prime contractor's markup should be viewed as a lower (upper) bound for their actual markups when the subcontracting policy is more (less) stringent.

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 change of scale in all DBE 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, and *Winning Bid* refers to the simulated winning bid. *Project Cost* corresponds to the simulated project costs, and *DBE Cost* is the portion of the winning bid paid to DBE subcontractors. *Markup* is the markup term, which contains the prime contractor's and non-DBE subcontractors' profits.

Table 8 displays the results of the policy experiments. As a general trend, increasing the subcontracting requirements decreases markups, whereas 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 lead to higher project costs, lower markups, and higher winning bids. These effects are modest, though, because the fine function affects only the decisions of prime contractors that would otherwise subcontract below the DBE subcontracting requirement.

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 0.8 percentage point (or 8.9 percent) increase in the average share of work allocated to DBE subcontractors and a $\$43,371$ (or 13.8 percent) increase in the average amount awarded to DBE subcontractors. These increases correspond to a $\$11,265$ (or 0.2 percent) increase in the average procurement cost and a $\$4,351$ (or 0.6 percent) decrease in average markups.

Counterfactual Quotas

So far, my analysis shows that using fines to enforce DBE subcontracting requirements can lead to higher DBE subcontracting shares. However, the fine does not guarantee that prime contractors fulfill the subcontracting requirements because 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. For simplicity, I fix the quota level across all simulated auctions.

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 because 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 markups. 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).

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 $P\left(s_i\right)$, prime contractors now face a subsidized pricing function of $\left(1 - sub\right) P\left(s_i\right)$, where $sub \in [0, 1]$ is the fraction of the total DBE cost paid by the government. To account for 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 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.

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]

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 contains the policy comparisons. In general, many of the outcomes under subsidies and quotas are similar to those of subcontracting requirements. Relative to subcontracting requirements, subsidies result in lower winning bids, higher markups, and lower procurement costs, where procurement costs include the cost of the subsidy. However, subsidies also result in lower payments to DBE subcontractors. These results are intuitive because 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 amount of money given to DBE subcontractors, whereas subsidies are best for governments pursuing policies with lower procurement costs.

8 Conclusion

This article 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.

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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 web Appendix.

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 13.8 percent while increasing procurement costs by only 0.2 percent. These results suggest that New Mexico's subcontracting requirements, although effective in increasing DBE subcontractor utilization, were not responsible for large increases in procurement costs.

Although my analysis focuses on the DBE program in New Mexico, the markup reduction from a common subcontractor pool is not unique to DBEs and can be applied to other settings where firms are required to utilize a common pool of approved subcontractors. A common subcontractor pool can potentially arise for different classes of disadvantaged firms, such as small businesses and veteran-owned firms, and even firms that are not disadvantaged. There are a few open questions. Because of the complexity associated with solving dynamic auctions, I do not estimate a model with dynamic relationship formation between prime contractors and DBE subcontractors. A dynamic model could shed light on the long-run effectiveness of DBE and similar programs as relationships build between different types of firms. Because information on the DBE subcontracting market is limited, I do not model the DBE subcontracting market's structure or any strategic replies DBE firms may have in their pricing when there is a requirement. On one hand, there is a possibility that requirements give DBEs market power, which they might exploit to charge higher prices. On the other hand, requirements might encourage entry and result in a DBE subcontracting market with more competitive pricing. An exploration of these channels could be a promising avenue for future research.

Appendix A

This Appendix contains proofs of the propositions and corollaries in Section 3, along with properties of the optimal DBE subcontracting decision.

Properties of the Optimal DBE Subcontracting Decision

Second-Order Conditions

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

$$-P''\left(s_i\right) - \varphi''\left(s_i; \overline{s}\right) < 0.$$

Observe that this condition is satisfied by the convexity assumption on φ and P.

Comparative Statics

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

$$1 = P''\left(s\left(c_i;\overline{s}\right)\right) s'\left(c_i;\overline{s}\right) + \varphi''\left(s\left(c_i;\overline{s}\right);\overline{s}\right) s'\left(c_i;\overline{s}\right).$$

After some algebraic manipulation, the above equation reduces to

$$s'\left(c_i;\overline{s}\right) = \frac{1}{P''\left(s\left(c_i;\overline{s}\right)\right) + \varphi''\left(s\left(c_i;\overline{s}\right);\overline{s}\right)},$$

which is increasing given the second-order conditions.

Proofs

Proof of 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

$$\begin{aligned} \Pi\left(c_i;\overline{s}\right) &= \\ & \left(b\left(c_i;\overline{s}\right) - c_i\left(1 - s\left(c_i;\overline{s}\right)\right) - P\left(s\left(c_i;\overline{s}\right)\right) - \varphi\left(s\left(c_i;\overline{s}\right);\overline{s}\right)\right) \\ & \times\left(1 - F\left(c_i\right)\right)^{N-1}. \end{aligned} \tag{9}$$

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

$$\Pi\left(c_i;\overline{s}\right) = \max_{\{b_i,s_i\}}\left(b_i - c_i\left(1-s_i\right) - P\left(s_i\right) - \varphi\left(s_i;\overline{s}\right)\right)\left(1 - F\left(b^{-1}\left(b_i\right)\right)\right)^{N-1}.$$

Apply the envelope theorem to get

$$\left.\frac{d}{dc}\Pi\left(c;\overline{s}\right)\right|_{c=c_i} = \left(s\left(c_i;\overline{s}\right) - 1\right)\left(1 - F\left(c_i\right)\right)^{N-1}.$$

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

$$\Pi\left(c_i;\overline{s}\right) = \Pi\left(\overline{c};\overline{s}\right) + \int_{c_i}^{\overline{c}}\left(1 - s_t\left(\tilde{c};\overline{s}\right)\right)\left(1 - F\left(\tilde{c}\right)\right)^{N-1} d\tilde{c}. \tag{10}$$

Given that I assume (and by the derivation of the bid function, show that) 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 $\Pi\left(\overline{c};\overline{s}\right)=0$ and equate the right hand side of equations (9) and (10) to get the optimal bid function in equation (6). ☐

Remark 1. To use the inverse bid function, 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 $s\left(c_i;\overline{s}\right)<1$, using the results from equation (5). When $s\left(c_i;\overline{s}\right)=1$, no bidder will bid over $\overline{\phi}$, which is their project cost in equilibrium. Otherwise, there is a profitable deviation in which they reduce their bid and increase the probability of winning. The derived bid function has this property built into it.

Remark 2. It is also important to understand the shape of the bid function, as there is a region where two different draws of c_i could lead to the same bid. Specifically, my previous remark suggests that the optimal bid function will be flat in c_i whenever $s\left(c_i;\overline{s}\right)=1$ and increasing in c_i whenever $s\left(c_i;\overline{s}\right)\in[0,1)$. This result is intuitive because 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.

Proof of Proposition 2. By the first-order conditions on optimal DBE subcontracting,

$$c_i=P'\left(s_i\right)+\varphi'\left(s_i;\overline{s}\right).$$

Given the assumption $s\left(c_i;0\right)\neq s\left(c_i;\overline{s}\right)$, it must be the case that $\varphi'\left(s_i;\overline{s}\right)<0$. When that inequality holds, prime contractors find it optimal to increase their DBE shares s_i when there is a DBE subcontracting requirement. There are now three possible cases for $s\left(c_i;0\right)$ and $s\left(c_i;\overline{s}\right)$[21]: both solutions are interior solutions, one of the two solutions is an interior solution and the other is a corner solution, or both solutions occur at different corners. In either of these three cases $s\left(c_i;0\right)<s\left(c_i;\overline{s}\right)$. ☐

Proof of Corollary 1. Suppose bidder i wins an auction with a bid of b. Without subcontracting requirements, he would choose shares, $s\left(c_i;0\right)$, such that

$$s\left(c_i;0\right)\in\arg\max_{s_i}\left\{b-c_i\left(1-s_i\right)-P\left(s_i\right)\right\},$$

---

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

or analogously,

$$s\left(c_i;0\right)\in\arg\min_{s_i}\left\{c_i\left(1-s_i\right)+P\left(s_i\right)\right\}.$$

Define $C\left(s_i;0\right)=c_i\left(1-s_i\right)+P\left(s_i\right)$ as the project cost of bidder i when there are no DBE subcontracting requirements, and consider the optimal share with subcontracting requirements, $s\left(c_i;\overline{s}\right)$. Because $s\left(c_i;0\right)$ is the minimizer of $C\left(\cdot;0\right)$, $C\left(s\left(c_i;0\right);0\right)\leq C\left(s\left(c_i;\overline{s}\right);0\right)$. Because fines are non-negative, $C\left(s\left(c_i;\overline{s}\right);0\right)\leq C\left(s\left(c_i;\overline{s}\right);0\right)+\varphi\left(s\left(c_i;\overline{s}\right);\overline{s}\right)=\phi\left(c_i;\overline{s}\right)$. ☐

Proof of Corollary 2. Proposition 2 implies that $s\left(c_i;0\right)\leq s\left(c_i;\overline{s}\right)$ for all non-DBE costs, c_i. Therefore, markups are weakly lower with DBE subcontracting requirements because

$$\int_{c_i}^{\overline{c}}\left(1-s\left(\tilde{c};\overline{s}\right)\right)\left(1-F\left(\tilde{c}\right)\right)^{N-1}d\tilde{c}\leq\int_{c_i}^{\overline{c}}\left(1-s\left(\tilde{c};0\right)\right)\left(1-F\left(\tilde{c}\right)\right)^{N-1}d\tilde{c}.$$

☐

Appendix B

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

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

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

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

Observe that restricting $\alpha_0 > 0$, $\alpha_1 > 0$, $\alpha_2 > 0$ and $\alpha_3 > 0$ will generate a DBE pricing function that is convex and increasing in the DBE share for $s_i \in [0,1)$. Similarly, restricting $\gamma > 0$ will produce a fine function that is convex and non-increasing for $s_i \in [0,1]$. In estimation, I restrict the structural parameter values to the aforementioned range of possible values to maintain those properties across parameter guesses.

Standard Errors and Optimal Weighting Matrix

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

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

with

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

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

and

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

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

In practice, 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

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

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

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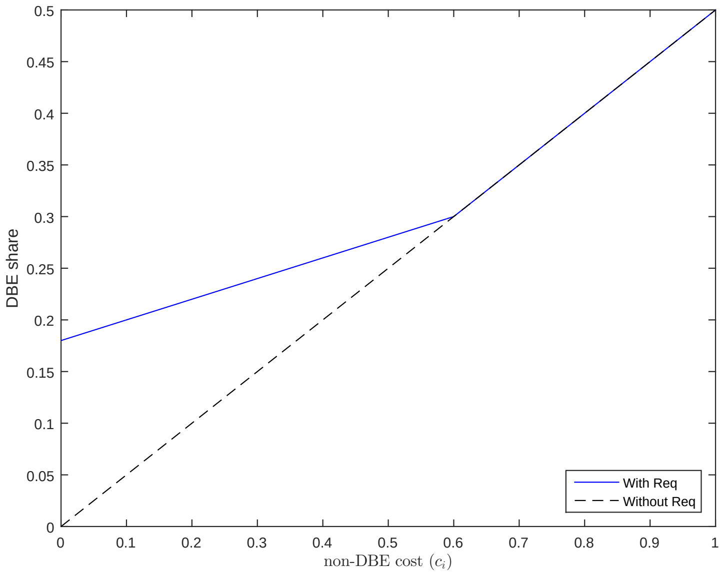

Figure 1: DBE Share Function

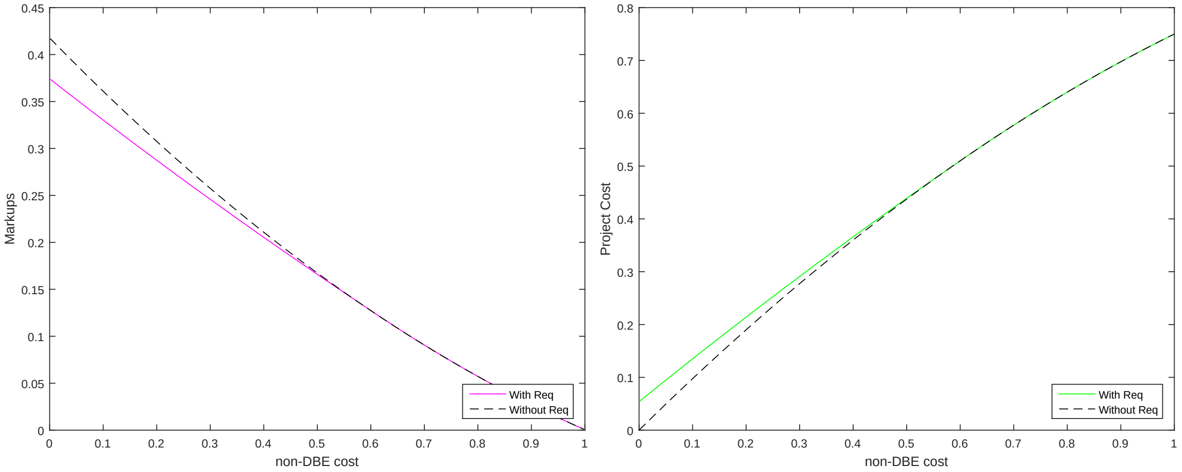

Figure 2: DBE Share Functions with Quotas and Subsidies

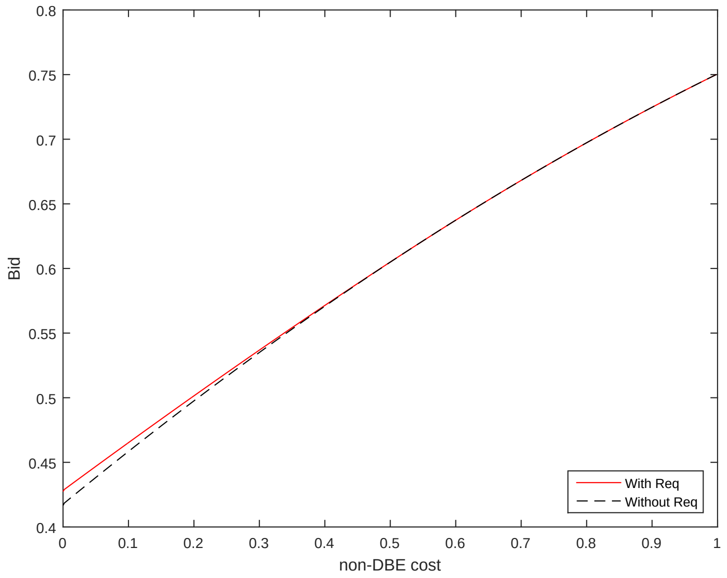

Figure 3: Bid Function

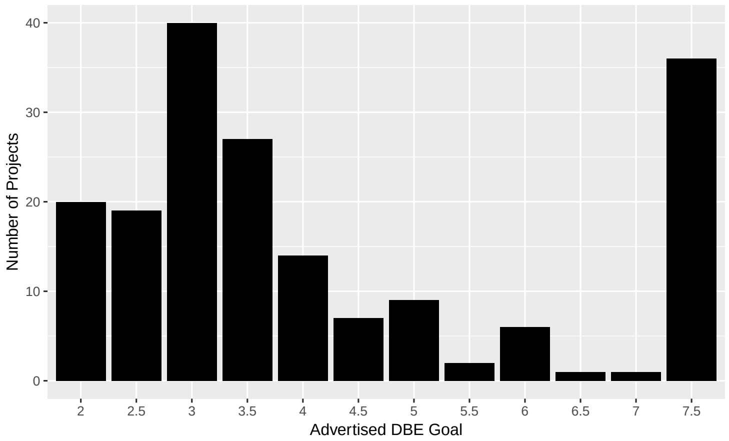

Figure 4: Number of Projects by DBE Goal

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

Table 1: Summary Statistics

	With Req.		W/o Req.		Total	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Eng. Estimate (1000s)	5530.86	6682.41	4120.84	6975.37	4808.84	6861.21
Winning Bid (1000s)	5256.19	6843.40	3712.46	6019.81	4465.70	6472.43
Bidders	4.64	1.94	4.14	1.96	4.38	1.96
Subprojects	9.83	5.12	7.47	4.78	8.62	5.08
DBE Share (%)	9.15	7.20	4.30	5.77	6.67	6.94
DBE Req. (%)	4.20	1.91	0.00	0.00	2.05	2.49
Share-Req. Gap (%)	4.95	6.91	4.30	5.77	4.62	6.35
Comply if Req.	0.91	0.29			0.91	0.29
Number of Contracts	182		191		373	

Table 2: OLS Regression of the Winning Bids

	Dependent variable:		
	log(Winning Bid)		
	(1)	(2)	(3)
log(Engineer's Estimate)	0.971***	0.926***	0.927***
	(0.009)	(0.021)	(0.021)
DBE Req (%)	−0.002	0.001	0.001
	(0.003)	(0.004)	(0.003)
log(Length + 1)		0.019	0.023*
		(0.014)	(0.013)
log(Planholders)		−0.064	−0.031
		(0.043)	(0.047)
log(Subprojects)		0.083***	0.082***
		(0.025)	(0.024)
Number of Licenses Required		0.043**	0.039**
		(0.018)	(0.018)
log(Working Days)		0.017	0.009
		(0.026)	(0.025)
Bidders		−0.024***	−0.017***
		(0.005)	(0.005)
Federal Highway		0.008	0.004
		(0.020)	(0.021)
Urban		−0.052*	−0.048
		(0.030)	(0.029)
Work Type/District Controls		X	X
Month/Year FEs			X
Observations	373	373	373
Adjusted R^2	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. Standard errors are robust.

Table 3: OLS Regressions of the DBE Shares

	Dependent variable:		
	DBE Share (%)		
	(1)	(2)	(3)
log(Engineer's Estimate)	0.308	−0.204	−0.139
	(0.306)	(0.559)	(0.530)
DBE Req (%)	1.101***	0.971***	0.922***
	(0.142)	(0.156)	(0.182)
log(Length + 1)		−0.298	−0.205
		(0.460)	(0.459)
log(Planholders)		−1.190	1.540
		(1.626)	(1.952)
log(Subprojects)		2.209**	1.847**
		(0.865)	(0.869)
Number of Licenses Required		1.060	1.052
		(0.826)	(0.785)
log(Working Days)		−0.280	−0.533
		(0.610)	(0.608)
Bidders		0.003	−0.011
		(0.197)	(0.215)
Federal Highway		0.038	0.009
		(0.698)	(0.688)
Urban		1.847**	1.549*
		(0.841)	(0.871)
Work Type/District Controls		X	X
Month/Year FEs			X
Observations	373	373	373
Adjusted R^2	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. Standard errors are robust.

Table 4: OLS Regressions of the Share-Bidder Interaction

	Dependent variable:		
	log(Winning Bid)		
	(1)	(2)	(3)
log(Engineer's Estimate)	0.975***	0.928***	0.929***
	(0.008)	(0.021)	(0.021)
DBE Share (%)	−0.003	−0.004	−0.004*
	(0.003)	(0.003)	(0.002)
Bidders	−0.041***	−0.034***	−0.026***
	(0.007)	(0.007)	(0.006)
DBE Share × Bidders	0.001**	0.001**	0.001***
	(0.001)	(0.001)	(0.0005)
Project/Work Type/District Controls		X	X
Month/Year FEs			X
Observations	373	373	373
Adjusted R^2	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. Standard errors are robust.

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

	Coefficient	Standard Error
Constant	0.722	0.247
log(Engineer's Estimate)	0.937	0.021
log(Length + 1)	0.028	0.018
log(Subprojects)	0.077	0.028
Licenses	0.080	0.027
log(Working Days)	-0.003	0.014
Federal Highway	0.002	0.017
Urban	-0.040	0.027
District 2 - Roswell Area	-0.064	0.035
District 3 - Albuquerque Area	-0.066	0.023
District 4 - Las Vegas Area	0.168	0.038
District 5 - Santa Fe Area	-0.017	0.037
District 6 - Grants/Milan Area	-0.095	0.036
Bridge work	-0.077	0.036
Lighting	-0.139	0.035
Road Work	-0.022	0.026
Safety Work	-0.142	0.040
Stockpiling	0.359	0.091
σ_c	0.212	0.048

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

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

	Coefficient	Standard Error
σ_u		
Constant	-0.119	0.275
DBE Req (%)	-0.181	0.078
Pricing Constant (α_0)	0.252	0.115
s_i (α_1)	0.527	0.196
$\frac{s_i}{1-s_i}$ (α_2)	0.553	0.273
1/Subprojects ($\alpha_{3,1}$)	0.130	0.056
Rural ($\alpha_{3,2}$)	0.144	0.034
Fine Parameter (γ)	9.204	45.746

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

Table 7: Model Fit

	Actual	Predicted
With Req.		
Avg. DBE Share (%)	9.15	9.14
Sd. DBE Share (%)	7.20	7.49
Avg. Winning Bid (in Millions)	5.26	5.23
Sd. Winning Bid (in Millions)	6.84	6.26
Without Req.		
Avg. DBE Share (%)	4.30	4.55
Sd. DBE Share (%)	5.77	6.94
Avg. Winning Bid (in Millions)	3.71	3.79
Sd. Winning Bid (in Millions)	6.02	6.17

Note: The averages and standard deviations of the predicted and actual procurement outcomes.

Table 8: Counterfactual Goal Levels

	Increase (50%)	Baseline	Decrease (50%)	Elimination
DBE Share (%)	9.85	9.14	8.63	8.39
	(0.23)	(0.25)	(0.26)	(0.27)
Winning Bid (in 1000s)	5234.88	5226.01	5218.89	5214.75
	(207.67)	(207.40)	(207.08)	(206.84)
Project Cost (in 1000s)	4526.19	4511.43	4500.69	4495.82
	(176.60)	(175.95)	(175.44)	(175.16)
DBE Cost (in 1000s)	399.68	357.67	327.47	314.30
	(20.38)	(19.43)	(19.26)	(19.38)
Markup (in 1000s)	708.69	714.58	718.20	718.93
	(37.45)	(38.12)	(38.53)	(38.74)

Note: Average auction outcomes for different requirement levels on auctions with DBE subcontracting requirements. Project costs are the costs to complete the entire project, which account for DBE subcontracting. DBE costs are the average simulated DBE cost, and Markups are the profits of the winning prime contractor and its non-DBE subcontractors. Standard errors are in parentheses.

Table 9: Counterfactual Quota Levels

	0% Quota	5% Quota	10% Quota	15% Quota	20% Quota
DBE Share (%)	8.39	10.33	12.83	16.17	20.32
	(0.27)	(0.21)	(0.15)	(0.09)	(0.04)
Winning Bid (in 1000s)	5214.75	5248.08	5291.58	5350.23	5432.18
	(206.84)	(207.46)	(208.48)	(210.13)	(212.78)
Project Cost (in 1000s)	4495.82	4542.54	4603.50	4685.42	4797.48
	(175.16)	(176.24)	(177.89)	(180.46)	(184.40)
DBE Cost (in 1000s)	314.30	444.27	613.00	842.19	1138.92
	(19.38)	(19.34)	(24.10)	(33.58)	(46.22)
Markup (in 1000s)	718.93	705.53	688.09	664.81	634.70
	(38.74)	(37.71)	(36.49)	(34.97)	(33.14)

Note: Average auction outcomes for different quota levels on auctions with DBE subcontracting requirements. Standard errors are in parentheses.

Table 10: Counterfactual Subsidy Levels

	0% Subsidy	5% Subsidy	10% Subsidy	15% Subsidy	20% Subsidy
DBE Share (%)	8.39	9.46	10.70	12.10	13.69
	(0.27)	(0.29)	(0.30)	(0.32)	(0.34)
Winning Bid (in 1000s)	5214.75	5187.66	5156.36	5120.12	5078.10
	(206.84)	(205.71)	(204.41)	(202.90)	(201.14)
Project Cost (in 1000s)	4495.82	4478.77	4458.72	4435.09	4407.17
	(175.16)	(174.43)	(173.56)	(172.55)	(171.37)
DBE Cost (in 1000s)	314.30	369.20	434.47	512.97	606.61
	(19.38)	(21.97)	(24.96)	(28.40)	(32.40)
Markup (in 1000s)	718.93	708.90	697.64	685.03	670.93
	(38.74)	(38.33)	(37.86)	(37.31)	(36.66)
Subsidy Cost (in 1000s)	0.00	18.46	43.45	76.95	121.32
	(0.00)	(1.10)	(2.50)	(4.26)	(6.48)
Procurement Cost (in 1000s)	5214.75	5206.12	5199.81	5197.07	5199.42
	(206.84)	(206.45)	(206.15)	(205.97)	(206.00)

Note: Average auction outcomes for different subsidy levels on auctions with DBE subcontracting requirements. The subsidy cost is the average cost of the subsidy, and the procurement cost is the sum of the winning bid and subsidy cost. Standard errors are in parentheses.

Table 11: Policy Comparisons

	Quota	Subsidy
Δ Winning Bid (%)	0.024	-0.585
Δ DBE Cost (%)	1.704	-1.216
Δ Markup (%)	-0.099	-0.397
Δ Procurement Cost (%)	0.024	-0.339

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