# Resident Bid Preference, Affiliation, and Procurement Competition: Evidence from New Mexico

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**Abstract**

In public procurement auctions, governments typically offer preferences to qualified businesses in the form of bid discounts. Previous studies that examine how these bid preferences affect auction outcomes fail to address affiliation – a particular type of correlation among costs that can be generated in a public procurement setting. This paper addresses that issue by studying the joint effect of bid preferences and affiliation in project-completion costs on procurement auctions using novel data from the New Mexico Department of Transportation's Resident Preference Program. Bidders, heterogeneous in residency status, compete in an auction with endogenous entry and affiliated project-completion costs for the opportunity to complete a construction project. Here affiliation is modeled using copulas, and an empirical model is developed to disentangle a bidder's participation and bidding decisions. I find that accounting for affiliation in project-completion costs considerably changes the evaluation of how offering preferences to resident bidders affects the cost of procurement and the number of resident bidders who ultimately win these preference auctions. The estimates indicate that the New Mexico Department of Transportation can increase the current level of preference to increase the number of winning resident bidders without a major change in the cost of procurement.

## 1 Introduction

Procurement auctions are widely used by governments as a means of securing goods and services for the lowest possible price. Internationally, government procurement accounts for anywhere from 10 percent to 25

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percent of GDP, and in the Unites States alone, government spending on goods and services accounted for 15.2 percent of GDP in 2013, totaling $2.55 trillion[1]. Although price is a first-order concern in procurement auctions, governments typically offer preferential treatment to a certain subset of bidders. This treatment often takes the form of either a set-aside auction where the government sets aside particular projects for qualified bidders only or granting qualified bidders a discount on bids where the government will artificially lower the bid of a preferred bidder by a certain amount and pay the full price on the submitted bid. Both of these policies introduce inefficiencies in the auction, and these inefficiencies have been studied extensively in the literature[2].

The purpose of offering these types of bid preference programs is to encourage participation of a particular type of bidder. For example, California offers a bid discount to small businesses to encourage these business to bid on larger projects, and the Inter-American Development Bank occasionally offers a bid discount to domestic firms to encourage domestic development. The total effect of these programs, however, has been shown to be ambiguous. On one hand, offering a discount to a favored group of bidders increases the probability of the favored group winning, encouraging more participation and less aggressive bidding. On the other hand, bid preferences give non-favored bidders an incentive to bid more aggressively, increasing competition and potentially reducing favored participation. This type of tradeoff is highlighted in McAfee and McMillan (1989) where the authors show that the government can minimize procurement costs by choosing an optimal discount level when participation is fixed and in Corns and Schotter (1999) where the authors use experiments to show that preferences can lead to increases in cost effectiveness and the participation of preferred bidders[3]. Krasnokutskaya and Seim (2011) show that these effects are altered when participation is endogenous.

Another potential issue in evaluating these types of programs, which has largely been ignored by the bid preference literature, is the potential affiliation between the project-completion costs of bidders. These costs are private information and are typically taken to be independent, implying that a vendor that learns her own cost has no additional information on the costs of other bidders. In a procurement setting, there are a number of reasons why this independence assumption may not hold. For instance, vendors typically use the same subcontractors when submitting a bid, so vendors sharing subcontractors should have some form of dependence in their private information. Contractors may also buy raw materials from the same suppliers

[1]These numbers are taken from the World Bank national accounts data and OECD National Accounts data files.

[2]For a discussion on set-aside auctions and subsidies, see Athey et al. (2013) and Nakabayashi (2013). Papers discussing bid preferences include Krasnokutskaya and Seim (2011), Marion (2007), and Hubbard and Paarsch (2009).

[3]Additional studies that show the theoretical implications of granting preference to certain groups of bidders include Vagstad (1995) who extends the analysis of McAfee and McMillan (1989) to incentive contracts and Naegelen and Mougeot (1998) who extend the analysis of McAfee and McMillan (1989) to include objectives concerning the distribution of contracts over preferred and non-preferred bidders.

which again implies some dependence in project costs, especially if contractors are located near each other. In fact, 12 percent of items[4] on projects qualifying for bid preferences had at least two vendors bid the same amount in my data[5]. This statistic is problematic if costs are taken to be independent[6].

This paper makes two contributions to the bid preference literature. The first contribution is that I allow vendors to have affiliated private project-completion costs as detailed by Milgrom and Weber (1982) in a bid preference setting with endogenous entry[7]. Affiliation is a stronger notion of positive correlation, and it captures the intuition that vendor costs may be related to each other. Using copula methods developed by Hubbard, Li, and Paarsch (2012) and extended by Li and Zhang (2013), I show how affiliation and bid preference *jointly* affect procurement auctions, and to my knowledge, this is the first paper to empirically do so. The second contribution is that I address the relationship between bid preference and affiliated costs using novel procurement data from the New Mexico Department of Transportation (NMDOT). New Mexico is unique in that it is one of the few states that offers firms qualifying as "residents" a 5 percent bid discount on state-funded projects. Affiliation is critical in a setting where preference is given to residents. In particular, firms located closely to each other are more likely to buy from the same suppliers and use similar subcontractors, implying a higher degree of affiliation in costs.

The empirical analysis begins with descriptive regressions on the bidding and entry behavior of resident and non-resident vendors. I document significant differences between these two types of vendors. Namely, the descriptive regressions show that resident vendors bid 24.8 percent higher than non-resident vendors on preference auctions, and that resident vendors are 24 percent less likely than non-resident vendors to enter any type of procurement auction. These differences in bidding and entry patterns between resident and non-resident vendors are suggestive of differences in project-completion and entry costs, motivating the need to allow vendors to be differentiated by residency status.

In order to then determine the extent to which affiliation is present in NMDOT construction contracts and investigate counterfactual discount and affiliation levels, an empirical model of bidding and endogenous entry is estimated using the data. The estimates confirm that the differences in resident and non-resident bidding and entry are due to differences in resident and non-resident project-completion and entry costs and suggest

[4]Items are portions of a construction project. The final bid is calculated as the sum of the bids on each item.

[5]See section 3.2 for more information on projects that qualify for preference, and see section 4 for a detailed description of the data.

[6]Correlations across bids can also be generated by unobserved project heterogeneity (project characteristics that are unobserved to the econometrician yet observed by all bidders). Section 7.2 presents evidence that supports the notion that affiliation outweighs unobserved project heterogeneity in this empirical setting. In other environments where unobserved auction heterogeneity dominates affiliation, econometric methods developed in Krasnokutskaya (2011) and empirical methods found in Hong and Shum (2002) and Haile et al. (2006) would be more suitable.

[7]This paper also complements the existing literature on auctions with endogenous entry. These papers include Athey et al. (2011),Li (2005) and Bajari and Hortacsu (2003)

that vendors do have affiliated project-completion costs. Counterfactual auctions using different discount levels show that New Mexico can increase the number of winning resident vendors without a major change in procurement costs by increasing the discount level. In particular, increasing the discount from 0 percent to 15 percent only increases the cost of the modal construction project by around 2 percent while increasing the expected fraction of resident winners by about 0.15. Counterfactual simulations under different affiliation levels reveal large changes in the procurement costs as vendor project-completion costs become more affiliated, highlighting the need to take affiliation into account when evaluating these preference programs.

The rest of this paper proceeds as follows. The next section defines affiliation and shows how it can affect the analysis of bid preferences. Section 3 provides the details of the New Mexico procurement process. Section 4 describes the data. Section 5 presents the theoretical framework by which I evaluate how affiliation affects bidding behavior, and section 6 shows how I estimate the theoretical model. Section 7 presents the empirical findings, while section 8 contains the counterfactual policy analysis. Section 9 concludes.

## 2 Importance of Affiliation

Affiliation is a concept that describes the relationship between two or more random variables. In particular, if two or more random variables are affiliated, then they exhibit some form of positive dependence. de Castro (2010) shows that affiliation is a sufficient condition for positive correlation, so affiliation can loosely be interpreted as a stronger form of positive correlation[8]. Formally, affiliation is defined as follows:

**Definition.** The density function $f : [\underline{c}, \overline{c}]^n \rightarrow \mathbb{R}_+$ is affiliated if $f(c) f(c') \leq f(c \wedge c') f(c \vee c')$, where $c \wedge c' = (\min\{c_1, c_1'\}, ..., \min\{c_n, c_n'\})$ and $c \vee c' = (\max\{c_1, c_1'\}, ..., \max\{c_n, c_n'\})$.

In a procurement setting, affiliation in project-completion costs means that when a vendor draws a high project-completion cost, it is more likely that competing vendors also have drawn high project-completion costs.

There are a couple of changes affiliation in project-completion costs introduces into procurement auctions with bid preferences relative to independent project-completion costs. One change is that affiliation causes bidders to bid more aggressively for low project-completion cost draws and less aggressively for high project-completion cost draws independent of the level of preference. The intuition here is that when a bidder draws a low project-completion cost in an auction with affiliation, other bidders are more likely to draw low project-completion costs, implying that bidding should be more aggressive. The same logic can be applied to a high

[8] See de Castro (2010) for a detailed discussion on the relationship between affiliation and other notions of positive dependence.

project-completion cost draw in that bidding should be less aggressive in an auction with affiliation since other bidders are more likely to have drawn high project-completion costs. Affiliation also changes the difference between how preferred and non-preferred bidders submit bids in preference auctions. Bid preferences drive a wedge between preferred and non-preferred bidders, meaning that preferred bidders bid more with the same project-completion cost than a non-preferred bidder with the same cost. Affiliation accentuates this difference since project-completion costs are more likely to be similar.

The empirical relevance of affiliation in a procurement setting common to NMDOT preference auctions is demonstrated by figure 1[9]. This figure plots the average cost of procurement (represented by the average winning bid) and the fraction of residents winning preference auctions against the discount level for the modal project qualifying for preference in the data. These auction outcomes are then compared against each other in two separate environments: one where project-completion costs are independent and the other where project-completion costs are affiliated[10].

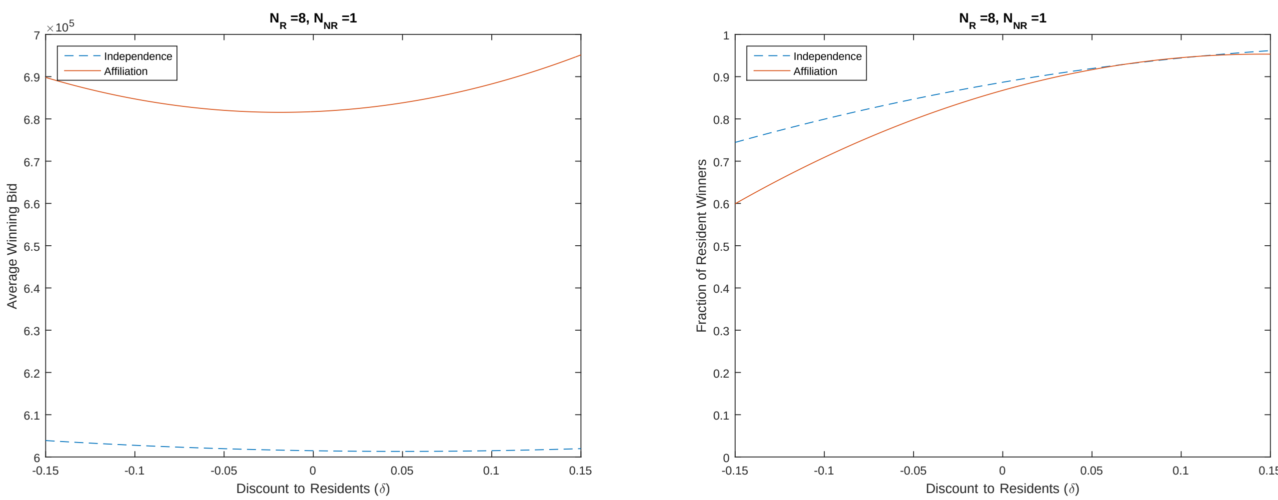


Figure 1: Average Winning Bid and Fraction of Resident Winners under Affiliation and Independence

Affiliation has a couple of implications for procurement costs and the fraction of resident auction winners under varying levels of resident preference. Concerning procurement costs, affiliation uniformly increases the cost to the government for procuring the same project relative to independence. This increase is due to the less aggressive bidding bought about by affiliation. Affiliation also causes the winning bid to be more sensitive to the level of preference, implying that the government is less free to set different levels of preference without impacting the winning bid. The extra sensitivity in winning bids to the preference level is generated by the

[9]For a detailed description of how these graphs are constructed, see section 8.

[10]In these figures, no affiliation corresponds to a dependence parameter of $\theta \approx 0$ and affiliation corresponds to the estimated dependence parameter of $\theta = 1.060$. For more information on the dependence parameter, see section 6.1.

increased difference in preferred-and non-preferred bidders caused by affiliation. Concerning the fraction of resident winners, affiliation increases the fraction of winning residents faster than independence when more preference is given to residents. The government can therefore increase the number of resident winners in these preference auctions more readily when costs are affiliated by offering higher discounts to resident bidders. These differences highlight the importance of considering affiliation when setting the amount of preference.

# 3 New Mexico Procurement

In this section, I describe the process by which the NMDOT awards their construction contracts. This process is important in understanding what firms know before bid submission and how the market for construction contracts is structured.

## 3.1 New Mexico Department of Transportation Letting Process

The Department of Transportation runs first-price sealed-bid procurement auctions on high-profile[11] construction and repair projects. Potential contractors and businesses submit a bid in a sealed envelope or secure online submission website to the Plans Specifications & Estimates (PS&E) Bureau, the Bureau responsible for managing the competitive bid process. The contractor or business with the lowest bid (usually) wins the contract, and the state pays the winner their bid.

Advertisement is crucial in the bidding process as it determines the information available to the bidder prior to bid submission. The Contracts Unit is responsible for gathering the necessary contract documents used in advertising. Each document is unique to the work required on each project and contains details such as the material requirements, construction methods, and basis of payment necessary for each contract. These details are summarized in an "Invitation for Bids" document that is released four weeks prior to bid opening.

Another important aspect of advertising is providing a rough approximation of contractors and businesses who could potentially bid for a contract. To advertise potential competitors, the PS&E Bureau publishes a list of "Planholders" ten days prior to bid opening. Status as a Planholder requires that the contractors and businesses provide some documented evidence that they have the contract documents either directly through the Bureau or through written communication. Moreover, failure to seek Planholder status results in the bid becoming unresponsive and subsequently rejected.

[11] The lowest estimated cost for the projects in this data is $78,910.

In addition to advertising through Planholders, the NMDOT occasionally holds pre-bid conferences to discuss any procurement requirements on selected projects. These conferences are usually held for larger or more complex projects, and are announced to all prospective bidders known to have requested the Invitation for Bids documents. Attending these conferences is costly. In particular, the firms who attend these conferences have generally invested some time in learning about the construction project in hopes of submitting a bid. The existence of these pre-bid conferences also rationalizes some of the sensitivity of submitted bids to the actual number of bidders since these conferences provide extra information on the number of actual bidders beyond planholder status[12].

## 3.2 Resident Preference Program

New Mexico offers bid preference to qualified resident contractors and businesses on construction projects using state funds[13]. The bid preference effectively applies a five percent discount on the total weight of all factors used in evaluating a proposal. If a contractor with this preference wins the procurement auction, the state will pay the full asking price before the discount was applied. To illustrate, suppose two bidders are bidding for a contract and the resident contractor bids $\$1,000,000$ and the out-of-state contractor bids $\$975,000$. After applying the five percent discount to the resident contractor, her bid is lowered to $\$950,000$, she wins the contract, and the state pays her $\$1,000,000$, the full bid price.

To qualify for the resident preference program, businesses and contractors must meet a certain list of conditions. In particular, businesses and contractors must have paid property taxes on real property owned in the state of New Mexico for at least five years prior to approval and employ at least 80 percent of its workforce from the state of New Mexico. The penalty for providing false information to the state of New Mexico is automatic removal of any preferences, ineligibility to apply for any more preference for at least five years, and administrative fines of up to $\$50,000$ for each violation. These penalties and restrictions ensure that contractors and businesses who qualify for resident preference are in fact residents and prevents outside businesses from falsely obtaining preference.

[12] If potential bidders were unaware of the actual number of bidders in an auction prior to submitting a bid, then there should be no correlation between the submitted bids and the actual number of bidders as potential bidders would take expectations over all possible competing bidders. As shown in table 4, there is a correlation between the number of bidders and submitted bids, suggesting that bidders are at least somewhat aware of the actual number of bidders.

[13] New Mexico does offer additional preference for veteran-owned businesses for some contracts. Since the invitation for bids document only makes provisions for resident bidders, I assume that no other preference program besides the resident program affects bidding for these particular types of contracts.

# 4 Data Description

The data is collected from a variety of documents from the New Mexico Department of Transportation. Roughly each month the NMDOT publishes the "Invitation For Bids" document mentioned in section 3.1. This document contains a list of available projects and project descriptions such as location, nature of the work, number of working days to complete the project, and project length. I use this document to obtain a set of observable characteristics about each individual project.

The NMDOT then publishes a list of Planholders for each project ten days prior to bid opening. Status as "Planholder" is essential in the letting process[14]. As previously mentioned, New Mexico law requires potential vendors seek status as a Planholder through either requesting a set of documents on which the contractor intends to bid through the NMDOT or submitting written communication that the contractor has received the necessary documents from another source. I use the contractors who are registered as Planholders as the set of potential bidders since this information is known prior to bidding and required to submit a valid bid[15].

Another document published by the NMDOT that is directly used in this analysis is the Apparent Low Bid document. Directly after bid opening, the NMDOT tabulates and publishes a list of bids received by the contractors. These tabulations are raw and do not include any bid discount that can potentially be applied to the received bid. I use these numbers as the bids received by the NMDOT from each contractor.

The final piece of data needed for this analysis is the list of vendors who qualify for resident preference. To obtain this list, I exploit the New Mexico Inspection of Public Records Act which allows anyone to view public documents. The data from this list provides the identity of the vendors who qualify for resident preference at the time of bidding.

# 5 Theoretical Model

This section provides the theoretical foundation by which the market for NMDOT construction contracts is analyzed. In order to maintain the main features of the market, I model New Mexico's market for construction services as a first-price sealed-bid procurement auction with asymmetric bidders, affiliated private values, and endogenous entry. The model proceeds in two stages as in Levin and Smith (1994), Krasnokutskaya and Seim

[14] For more information the planholder requirement, see the NMDOT website.

[15] This measure is not perfect. Some contractors seek Planholder status after the list is published, resulting in a larger set of potential bidders than what is represented on the Planholder document. I therefore include any actual bidders that do not appear in the planholder document in the set of potential entrants. Moreover, the set of planholders typically contains firms that do not have the means to bid as a main contractor. In order to get a more accurate set of firms who could potentially bid, I do not include firms who fail to bid during the sample period. Finally, I drop projects with a large ($> 15$) number of planholders for computational reasons (about 5 percent of the total number of projects).

(2011), and Li and Zhang (2013). In the first stage, potential resident and non-resident bidders decide whether to pay the bid submission cost and participate in the auction. Bidders will enter if their expected profits from participation exceed their cost of preparing a bid. The entry stage captures the effort required to gather information about the project and the opportunity cost of time which, in the New Mexico setting, is analogous to reading the invitation for bids, requesting project information and attending any conferences. In the second stage, bidders are informed of the identity and number of actual competitors, draw their project completion costs from an affiliated cost distribution, and submit a bid for the project. The assumption that bidders learn the set of actual bidders prior to bid submission is institutionally represented by the pre-bid conferences. It is important to note that affiliation in project completion cost gives bidders extra information on the opponent's project completion costs which makes sense if bidders are located close to each other and share similar subcontractors.

## 5.1 Environment

To formalize ideas, $N_R$ potential resident bidders and $N_{NR}$ potential non-resident bidders compete in a first-price sealed-bid procurement auction for the completion of one indivisible construction project. Resident and non-resident bidders are risk neutral and draw bid preparation costs, $k_i$, independently from the distribution $G_k^m(\cdot)$ where $m \in \{R, NR\}$ denotes vendor $i$'s group affiliation. Project completion costs, $c_i$, are drawn from the joint distribution $F_{\boldsymbol{c}}(\cdot, \ldots, \cdot)$ with support $[\underline{c}, \overline{c}]^n$ where $n$ is the total number of actual bidders. I allow the project completion cost distributions to be affiliated, but it is important to note that I assume project completion costs are independent of bid preparation costs[16]. These distributions are common knowledge to every potential bidder.

Additionally, resident vendors in auctions that use state funds receive a discount of $\delta$ on their submitted bid. In terms of the model, the auctioneer will lower every resident bid by a factor of $(1-\delta)$ when comparing it against a non-resident bid in a preference auction, so a resident will win if her bid is less than the lowest competing resident bid and the lowest competing non-resident bid scaled by a factor of $\frac{1}{1-\delta}$. The value of the discount is 5 percent for New Mexico residents.

[16]This assumption implies that bidders do not base entry decisions on their project completion costs. Samuleson (1985) discusses the opposite case where bidders are completely informed of their project completion costs prior to entry, and Roberts and Sweeting (2010) discuss the intermediate case where bidders are partially informed. Within the independent private values paradigm, Li and Zheng (2009) provide evidence that supports a model in which bidders are initially uniformed prior to entry in a procurement setting.

### 5.2 Bidding

After bidders learn of their project completion costs and number of actual entrants, bidders submit their bids to complete the construction contract. I restrict attention to group-symmetric equilibria as in Krasnokutskaya and Seim (2011) where bidders of each group $m$ follow potentially different monotone and differentiable bid functions $\beta_m(\cdot) : [\underline{c}, \overline{c}] \to \mathbb{R}_+$. In particular, a bidder of group $m$ solves the following optimization problem to determine the equilibrium bids:

$$\pi(c_i; n_{NR}, n_R) = \max_{b_i} (b_i - c_i) \Pr\left( (1-\delta)^{D_R} b_i < B_j \, \forall j \in NR, (1-\delta)^{-D_{NR}} b_i < B_l \, \forall l \in R \mid c_i \right)$$

where $\pi(c_i; n_{NR}, n_R)$ is the value function, $b_i$ is the bid choice of bidder $i$, $B_j$ and $B_l$ are the competing bids, $D_m$ is an indicator variable that takes on a value of one if vendor $i$ is associated with group $m$ and zero otherwise, and $\delta = 0$ if the auction is not a preference auction. The objective function illustrates how firms view preference when submitting a bid. For positive $\delta$, preference increases the probability of a resident beating a non-resident bidder without requiring the resident bidder to submit a lower bid. Residents therefore have a higher probability of winning a preference auction with the same choice of $b_i$ when compared to a non-preference auction yet face the same payment if they win[17].

Let $n_m$ denote the actual number of bidders in group $m$. Furthermore, let $\bar{F}_{\boldsymbol{c}_{-i}}(c_1, \ldots, c_{i-1}, c_{i+1}, \ldots, c_n \mid c_i) = \Pr(C_1 > c_1, \ldots, C_{i-1} > c_{i-1}, C_{i+1} > c_{i+1}, \ldots, C_n > c_n \mid c_i)$ be the joint survival function of project completion cost signals without bidder $i$ conditional on bidder $i$'s signal [18], and define $\boldsymbol{\beta}_{NR}^{-1}\left((1-\delta)^{D_R} b_i\right) = \left(\beta_{NR}^{-1}\left((1-\delta)^{D_R} b_i\right), \ldots, \beta_{NR}^{-1}\left((1-\delta)^{D_R} b_i\right)\right) \in \mathbb{R}^{n_{NR}-D_{NR}}$ as a vector that collects the inverse bid functions of non-residents and $\boldsymbol{\beta}_{R}^{-1}\left((1-\delta)^{-D_{NR}} b_i\right) = \left(\beta_{R}^{-1}\left((1-\delta)^{-D_{NR}} b_i\right), \ldots, \beta_{R}^{-1}\left((1-\delta)^{-D_{NR}} b_i\right)\right) \in \mathbb{R}^{n_R - D_R}$ as a vector that collect the inverse bid function of residents. The first order condition that charac-

[17] This intuition assumes that all else (opposing bids, object being auctioned, etc.) is equal.

[18] See section 6.1 for a detailed description on how to write the conditional survival function in terms of the cumulative density function

terizes the optimal bid is then given by

$$\begin{aligned}
0 &= (b_i - c_i) \\
&\times \left[ \sum_{j=1}^{n_{NR}-D_{NR}} \bar{F}_{\boldsymbol{c}_{-i},j} \left( \boldsymbol{\beta}_{NR}^{-1} \left( (1-\delta)^{D_R} b_i \right), \boldsymbol{\beta}_R^{-1} \left( (1-\delta)^{-D_{NR}} b_i \right) \mid c_i \right) \right. \\
&\times \beta_{NR,1}^{-1} \left( (1-\delta)^{D_R} b_i \right) (1-\delta)^{D_R} \\
&+ \sum_{j=n_{NR}-D_{NR}+1}^{n-1} \bar{F}_{\boldsymbol{c}_{-i},j} \left( \boldsymbol{\beta}_{NR}^{-1} \left( (1-\delta)^{D_R} b_i \right), \boldsymbol{\beta}_R^{-1} \left( (1-\delta)^{-D_{NR}} b_i \right) \mid c_i \right) \\
&\times \left. \beta_{R,1}^{-1} \left( (1-\delta)^{-D_{NR}} b_i \right) (1-\delta)^{-D_{NR}} \right] \\
&+ \bar{F}_{\boldsymbol{c}_{-i}} \left( \boldsymbol{\beta}_{NR}^{-1} \left( (1-\delta)^{D_R} b_i \right), \boldsymbol{\beta}_R^{-1} \left( (1-\delta)^{-D_{NR}} b_i \right) \mid c_i \right)
\end{aligned}$$

where $\bar{F}_{\boldsymbol{c}_{-i},j}\left(\cdot,\ldots,\cdot \mid c_i\right)$ is the partial derivative of the conditional survival function with respect to the $j$'th coordinate, $\beta_{NR,1}^{-1}(\cdot)$ is the partial derivative of a non-resident's inverse bid function with respect to its first coordinate, and $\beta_{R,1}^{-1}(\cdot)$ is the partial derivative of a resident's inverse bid function with respect to its first coordinate. These first order conditions form a system of differential equations that characterize the equilibrium bids.

Affiliation and bid preferences both have implications for equilibrium bidding in the second stage. Affiliation determines how aggressively bidders bid given their cost realization. Indeed, a bidder who draws a low (high) cost when costs are affiliated would be less (more) willing to bid higher than if costs were independent since affiliation makes it more likely that competing bidders have also drawn low (high) costs. Bid preferences drives a wedge between resident and non-resident bidders in the sense that residents will bid less aggressively than non-residents to account for the fact that residents have their bid discounted, and this wedge is amplified when costs are affiliated. The interaction of these two forces determine the outcome of a preference auction.

A complete characterization of the bidding equilibrium requires a specification of boundary conditions. Following the results of Hubbard and Paarsch (2009) and Krasnokutskaya and Seim (2011) I impose four group specific boundary conditions.

### 5.2.1 Left Boundary Condition

The left boundary condition requires that bidders who draw the lowest project completion cost submit the same bid when bid preferences are taken into account. Therefore, the left boundary condition for resident bidders is as follows:

$$\beta_R^{-1}\left((1-\delta)\,\underline{b}\right)=\underline{c}.$$

Likewise, the left boundary condition for non-resident bidders is

$$\beta_{NR}^{-1}\left(\underline{b}\right)=\underline{c}$$

where $\underline{b}$ is the common low bid.

#### 5.2.2 Right Boundary Condition

The right boundary condition places restrictions on bidding behavior at the highest possible project completion cost draw. This condition can loosely be interpreted as bidders who draw the highest project completion cost bid their project completion costs while making any necessary adjustments for the group affiliation of the competing bidders. The right boundary condition for resident bidders is formally

$$\beta_R^{-1}\left(\overline{b}\right)=\overline{c}$$

where $\overline{b}=\overline{c}$ if $n_R>1$ and $\overline{b}=\arg\max_b\left[(b-\overline{c})\Pr\left((1-\delta)\,b<b_j\,\forall j\in NR\mid\overline{c}\right)\right]$ if $n_R=1$. That is to say, if there is only one resident bidder on a project, she will choose a bid that maximizes her expected profits since the discount may lower her bid enough to be competitive with the non-resident bidders. The right boundary condition for non-resident bidders is taken to be

$$\beta_{NR}^{-1}\left(\overline{c}\right)=\overline{c}.$$

Observe that bid preference introduces another equilibrium feature mentioned by Hubbard and Paarsch (2009) and Krasnokutskaya and Seim (2011). In particular, if a non-resident draws a project completion cost $c\in\left[\frac{\overline{b}}{(1-\delta)},\overline{c}\right]$, then she also bids her project completion cost. Note that a project completion cost draw in this region for a non resident will never win the auction, yielding a payoff of zero as long as the non-resident bidder does not bid below her cost. Since bidders are indifferent between not winning an auction and winning an auction with a bid equal to their cost, this assumption can be made without changing the equilibrium payoffs.

Existence and uniqueness is important when empirically implementing these types of auctions. Existence ensures that there is, in fact, a solution to the auction game, while uniqueness ensures that the bidders are playing one equilibrium as opposed to potentially multiple different equilibria. Reny and Zamir (2004) show that a monotone pure strategy equilibrium exists in a more general setting than this type of auction. Uniqueness follows from Theorem 1 in Lebrun (2006) once addition structure is imposed on the conditional survival function[19].

## 5.3 Entry

In the entry stage, firms make participation decisions based on their knowledge of the number of potential entrants of each group, their knowledge of their own entry cost $k_i$ and their knowledge of the distributions of project completion costs and bid preparation costs. Ex ante expected profits are calculated as

$$\Pi_m\left(N_m, N_{-m}\right) = \sum_{n_m - 1 \subseteq N_m, n_{-m} \subseteq N_{-m}} \int_{\underline{c}}^{\overline{c}} \pi\left(c_i; n_m, n_{-m}\right) dF_c^m\left(c_i\right) \Pr\left(n_m - 1, n_{-m} \mid N_m, N_{-m}\right)$$

where the $-m$ subscript indicates the bidders not affiliated with the group of bidder $i$ and $F_c^m(\cdot)$ is the marginal project completion cost distribution of group $m$[20]. These profits are only a function of the observed number of potential bidders since the number of potential bidders and the bid preparation cost are the only payoff relevant information available before entry. Also note that the subscript is group specific since, assuming the degree of affiliation is the same across groups, members of the same group face the same ex-ante expected profits. The group specific equilibrium entry probabilities $p_m$ are determined by the known entry cost distribution. That is

$$p_m = \Pr\left(k_i < \Pi_m\right) = G_k^m\left(\Pi_m\right)$$

where $G_k^m(\cdot)$ is the marginal distribution of bid-preparation costs for a bidder in group $m$, and the above equality is formed using the equilibrium assumption of belief consistency. Existence of threshold probabilities $p_m$ that satisfy the above equation are guaranteed through an application of Brouwer's fixed point theorem[21].

[19] In particular, the conditional survival function must be log concave. This structure is imposed in section 6.1

[20] When computing these profits, I have to account for the case where no competing bidders enter the auction. This case is problematic since the NMDOT does not explicitly post a reserve price. The NMDOT does, however, reserve the right to reject all bids if the lowest price is excessively high. To capture this power to reject bids, I employ an assumption made by Krasnokutskaya and Seim (2011) in that I assume firms compete against the government (represented by a resident bidder) when faced with no other competition.

[21] Uniqueness, however, is not guaranteed and must be verified through simulation.

# 6 Empirical Model and Estimation

While the theoretical model provides a foundation for understanding the market for NMDOT procurement contracts, it does not lend itself to estimation. This section places additional parametric assumptions on the theoretical model to produce an empirical model that can be estimated from the data. I first discuss how affiliation is modeled using copulas. Next, I describe the remaining parametric assumptions and estimation routine. I also highlight how affiliation is parametrically identified through my estimation procedure.

## 6.1 Copula Representation

A major difficulty in implementing empirical auction models with affiliation is dealing with the joint cost distribution. To overcome this difficulty, I rely on copula methods as developed by Hubbard, Li, and Paarsch (2012). Copulas are an expression of the joint distribution of random variables as a function of the marginals. Formally, if $c_1, c_2, \ldots, c_n$ are $n$ possibly correlated random variables with marginal distributions $F_c^1(c_1), F_c^2(c_2), \ldots, F_c^n(c_n)$ respectively, then the joint distribution can be written as a function of the marginal distributions as

$$F_{\boldsymbol{c}}\left(c_1, c_2, \ldots, c_n\right) = \boldsymbol{C}\left[F_c^1\left(c_1\right), F_c^2\left(c_2\right), \ldots, F_c^n\left(c_n\right)\right]$$

where $C\left[\cdot, \ldots, \cdot\right]$ is the copula function.

The particular type of copula I use to represent the joint cost distribution of resident and non-resident bidders is a Clayton copula. This type of copula has the following closed-form representation:

$$\boldsymbol{C}\left[F_c^1\left(c_1\right), F_c^2\left(c_2\right), \ldots, F_c^n\left(c_n\right)\right] = \left(\sum_{i=1}^{n} F_c^i\left(c_i\right)^{-\theta} - n + 1\right)^{-\frac{1}{\theta}}$$

where $\theta \in [-1, \infty) \setminus \{0\}$ is the dependence parameter. Besides having a tractable representation, Clayton copulas are useful in the sense that affiliation only requires $\theta$ to be greater than zero[22]. Moreover, $\theta$ has the nice interpretation that a higher value of $\theta$ implies a higher degree of affiliation between the random variables, so $\theta$ contains all of the relevant information on cost dependence.

Since this paper focuses on procurement auctions, the conditional survival function is the distribution of interest. I use two results from Hubbard, Li, and Paarsch (2012) to construct an expression for the conditional survival function using copulas:

[22] For a formal proof of this statement, see Muller and Scarsini (2005)

**Result 1:**

The survival function, $\bar{F}_{\boldsymbol{c}}(c_1, c_2, \ldots, c_n)$, can be written as

$$\begin{aligned}
\bar{F}_{\boldsymbol{c}}(c_1, c_2, \ldots, c_n) &= \Pr(C_1 > c_1, C_2 > c_2 \ldots, C_n > c_n) \\
&= 1 - \sum_{i=1}^{n} \Pr(C_i < c_i) + \sum_{1 \le i < j \le n} \Pr(C_i < c_i, C_j < c_j) \\
&- \cdots + (-1)^n \Pr(C_1 < c_1, C_2 < c_2 \ldots, C_n < c_n).
\end{aligned}$$

This result provides an expression of the survival function in terms of the cumulative density function (CDF) which has a copula representation. Let $\boldsymbol{S}\left[1 - F_c^1(c_1), 1 - F_c^2(c_2), \ldots, 1 - F_c^n(c_n)\right]$ denote the survival copula evaluated at the survival marginals. The first result shows that the survival copula can be expressed as follows:

$$\begin{aligned}
\boldsymbol{S}\left[1 - F_c^1(c_1), 1 - F_c^2(c_2), \ldots, 1 - F_c^n(c_n)\right] &= 1 - \sum_{i=1}^{n} \boldsymbol{C}\left[F_c^i(c_i)\right] + \sum_{1 \le i < j \le n} \boldsymbol{C}\left[F_c^i(c_i), F_c^j(c_j)\right] \\
&- \cdots + (-1)^n \boldsymbol{C}\left[F_c^1(c_1), \ldots, F_c^n(c_n)\right].
\end{aligned}$$

**Result 2:**

$\Pr(C_2 > c_2 \ldots, C_n > c_n \mid c_1) = \boldsymbol{S}_1\left[1 - F_c^1(c_1), 1 - F_c^2(c_2), \ldots, 1 - F_c^n(c_n)\right]$ where $\boldsymbol{S}_1[\cdot, \ldots, \cdot]$ is the partial derivative of the survival copula with respect to the first coordinate.

Result 2 shows that the conditional survival copula is equivalent to the partial derivative of the full survival copula with respect to the conditioning argument.

Given these two results, the second stage profits of bidder 1 can be rewritten using copulas as

$$\begin{aligned}
\pi(c_1; n_{NR}, n_R) &= \max_{b_1} (b_1 - c_1) \\
&\times \boldsymbol{S}_1\left[1 - F_c^{m_1}(c_1), 1 - F_c^{NR}\left(\beta_{NR}^{-1}\right), \ldots, 1 - F_c^{NR}\left(\beta_{NR}^{-1}\right), 1 - F_c^{R}\left(\beta_{R}^{-1}\right), \ldots, 1 - F_c^{R}\left(\beta_{R}^{-1}\right)\right]
\end{aligned}$$

where $m_1$ is the group affiliation of bidder 1, $\beta_{NR}^{-1} = \beta_{NR}^{-1}\left((1-\delta)^{D_R} b_1\right)$, and $\beta_{R}^{-1} = \beta_{R}^{-1}\left((1-\delta)^{-D_{NR}} b_1\right)$.

The first order conditions are now given by

$$
\begin{aligned}
& \boldsymbol{S}_1\left[1-F_c^{m_1}\left(c_1\right), 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), \ldots, 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), 1-F_c^{R}\left(\beta_{R}^{-1}\right), \ldots, 1-F_c^{R}\left(\beta_{R}^{-1}\right)\right] \\
= \; & \left(b_1-c_1\right)\Bigg[\left(n_{NR}-D_{NR}\right) \beta_{NR,1}^{-1}(1-\delta)^{D_R} f_c^{NR}\left(\beta_{NR}^{-1}\right) \\
& \times \boldsymbol{S}_{12}\left[1-F_c^{m_1}\left(c_1\right), 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), \ldots, 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), 1-F_c^{R}\left(\beta_{R}^{-1}\right), \ldots, 1-F_c^{R}\left(\beta_{R}^{-1}\right)\right] \\
& +\left(n_R-D_R\right) \beta_{R,1}^{-1}(1-\delta)^{-D_{NR}} f_c^{R}\left(\beta_{R}^{-1}\right) \\
& \times \boldsymbol{S}_{1n}\left[1-F_c^{m_1}\left(c_1\right), 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), \ldots, 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), 1-F_c^{R}\left(\beta_{R}^{-1}\right), \ldots, 1-F_c^{R}\left(\beta_{R}^{-1}\right)\right]\Bigg]
\end{aligned} \tag{1}
$$

where $f_c^m(\cdot)$ is the marginal probability density function (PDF) associated with the marginal CDF $F_c^m(\cdot)$.

## 6.2 Parametric Specifications

The size of the data requires that I take a parametric approach in estimating the theoretical model by placing additional parametric restrictions on the cost distributions given observable auction characteristics. Specifically, an auction, indexed by $w$, contains a vector of variables observable to the researcher $(\boldsymbol{x}_w, \boldsymbol{z}_w, n_{Rw}, n_{NRw}, N_{Rw}, N_{NRw})$ where $\boldsymbol{x}_w$ is a vector of auction-level observables that affect project completion costs, $\boldsymbol{z}_w$ is a vector of auction-level observables that affect bid preparation costs, $n_{Rw}$ and $n_{NRw}$ are the observed number of resident and non-resident entrants respectively and $N_{Rw}$ and $N_{NRw}$ are the advertised number of potential resident entrants and non-resident entrants respectively. In order to ensure that all costs remain positive, I assume that the marginal distribution of project-completion costs conditional on $\boldsymbol{x}_w$, $F_c^m(\cdot \mid \boldsymbol{x}_w)$, and the marginal distribution of bid-preparation costs given $\boldsymbol{z}_w$, $G_k^m(\cdot \mid \boldsymbol{z}_w)$, are log-normal.

I must also place parametric restrictions on the probability firms assign to the entry of competing firms. To this end, I assume that the entry probability $p_{mw}(\boldsymbol{x}_w, \boldsymbol{z}_w, N_{Rw}, N_{NRw})$ is characterized by a binomial distribution:

$$
\Pr\left(n_{Rw}, n_{NRw} \mid \boldsymbol{x}_w, \boldsymbol{z}_w, N_{Rw}, N_{NRw}\right)=\Pr\left(n_{Rw} \mid \boldsymbol{x}_w, \boldsymbol{z}_w, N_{Rw}, N_{NRw}\right) \times \Pr\left(n_{NRw} \mid \boldsymbol{x}_w, \boldsymbol{z}_w, N_{Rw}, N_{NRw}\right)
$$

where

$$
\Pr\left(n_{mw} \mid \boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right)=\begin{pmatrix} N_{mw} \\ n_{mw} \end{pmatrix}\left(p_{mw}\right)^{n_{mw}}\left(1-p_{mw}\right)^{N_{mw}-n_{mw}}
$$

and

$$p_{mw} = G_k^m \left( \Pi_{mw} \left( \boldsymbol{x}_w, N_{mw}, N_{-mw} \right) \mid \boldsymbol{z}_w \right). \tag{2}$$

This assumption on entry probabilities means that each firm independently calculates the probability that firms in their group and firms in their competing group enter the auction given their knowledge of the cost distributions. Note that equation 2 comes from the equilibrium condition that beliefs are consistent.

A major issue in empirically implementing the theoretical model is the presence of the inverse bid function in the first order conditions of the second-stage bidding problem. This complication requires that the inverse bid function be approximated for every set of second-stage parameter guesses. To address this issue, I rely on approximations[23] based on indirect methods introduced by (Guerre, Perrigne, and Vuong, 2000, henceforth abbreviated GPV) further extended by Krasnokutskaya (2011) for the case of unobserved auction heterogeneity and Hubbard, Li, and Paarsch (2012) for the case of affiliation using copulas. In particular, a firm's cost can be inferred from the observed bid distribution by noting that $F_b^m(b) = F_c^m\left(\beta_m^{-1}(b)\right)$ and $f_b^m(b) = f_c^m\left(\beta_m^{-1}(b)\right)\beta_{m,1}^{-1}(b)$[24]. Making these substitutions in the first order conditions of the second stage bidding problem obviates the need for estimating the inverse bid function when determining project-completion costs. As a result, I will now focus on the marginal distribution of bids, $F_b^m(\cdot \mid \boldsymbol{x}_w)$, instead of the marginal distribution of project completion costs, $F_c^m(\cdot \mid \boldsymbol{x}_w)$.

I impose my final set of parametric restrictions on the log-normal distribution of bids and bid-preparation costs. In particular, I assume that the log of the submitted bids takes the following form:

$$\log(b_{iw}) = \boldsymbol{x}_{iw}'\beta + \epsilon_{iw}^{m_i}$$

where

$$\epsilon_{iw}^{m_i} \mid \boldsymbol{x}_{iw} \sim \mathcal{N}\left(0, \exp\left(\boldsymbol{x}_{iw}'\sigma\right)^2\right)$$

$$\left(\epsilon_{1w}^{NR}, \ldots, \epsilon_{n_{NR}w}^{NR}, \epsilon_{n_{NR+1}w}^{R}, \ldots, \epsilon_{n_{NR}+n_{R}w}^{R} \mid \boldsymbol{x}_{iw}\right) \equiv \boldsymbol{\epsilon}_w \sim F_{\boldsymbol{\epsilon}_w}$$

$$F_{\boldsymbol{\epsilon}_w} = \boldsymbol{C}\left[F_{\epsilon_{1w}^{NR}}, \ldots, F_{\epsilon_{n_{NR}w}^{NR}}, F_{\epsilon_{n_{NR+1}}^{R}}, \ldots, F_{\epsilon_{n_{NR}+n_{R}}^{R}}\right].$$

[23]These methods are approximations because the boundary conditions may not hold. I rely on these particular methods because it allows me to include a richer set of auction-level observable characteristics in the bidding and entry stages without increasing the computational burden. It is important to note that these extra observables are important for this paper since any omitted variables would contribute to unobserved project heterogeneity instead of affiliation, and the central claim of this study is that affiliation is the main driver of any correlation in bidding patterns across vendors. For a paper that directly estimates bid functions from the cost distributions in a similar setting, see Li and Zhang (2013).

[24]For a complete description on how to approximate the inverse bid functions using GPV in this setting, see the appendix.

Likewise, the bid preparation costs are assumed to take the following form:

$$\log(k_{iw}) = \boldsymbol{z}'_{iw}\gamma + u^{m_i}_{iw}$$

where

$$u^{m}_{iw} \mid \boldsymbol{z}_{iw} \sim \mathcal{N}\left(0, \exp\left(\boldsymbol{z}'_{iw}\alpha\right)^2\right).$$

### 6.3 Estimation

The parameters of the empirical model are estimated using a generalized method of moments (GMM) approach. I essentially match the theoretical predictions of the empirical model to the data by selecting the parameter values that minimize the weighted distance between model moments and data moments. This subsection gives a general overview of how I construct the moment conditions and use them in estimation. For a more detailed explanation on how the moments are derived from the empirical model, see the appendix.

My first set of moment conditions are used to identify the parameters of the bid distribution. These moment conditions are

$$E\left[\boldsymbol{x}_{iw}\left(\log(b_{iw}) - \boldsymbol{x}'_{iw}\beta\right)\right] = 0 \tag{3}$$

and

$$E\left[\boldsymbol{x}_{iw}\left(\log(b_{iw}) - \boldsymbol{x}'_{iw}\beta\right)\left(\log(b_{iw}) - \boldsymbol{x}'_{iw}\beta\right)\right] = E\left[\boldsymbol{x}_{iw}\exp\left(\boldsymbol{x}'_{iw}\sigma\right)^2\right]. \tag{4}$$

Observe that equation 4 yields the standard deviation parameter, $\sigma$, and equations 3 and 4 yield the mean parameter, $\beta$.

In addition to identifying the parameters of the marginal distributions, the affiliation parameter, $\theta$, must also be identified through the moment conditions of the model. I identify this parameter by relying on methods developed by Oh and Patton (2013) to estimate copulas using method of moments. In particular, the degree of dependence between two random variables can be summarized by a statistic called Kendall's tau. This statistic's equation for Clayton copulas together with its closed form solution motivate the following moment condition:

$$\frac{\theta}{\theta+2} = 4E\left[\boldsymbol{C}\left[\Phi\left(\frac{\log(b_{iw}) - \boldsymbol{x}'_{iw}\beta}{\exp\left(\boldsymbol{x}'_{iw}\sigma\right)}\right), \Phi\left(\frac{\log(b_{jw}) - \boldsymbol{x}'_{jw}\beta}{\exp\left(\boldsymbol{x}'_{jw}\sigma\right)}\right)\right]\right] - 1 \quad i \neq j \tag{5}$$

where $\Phi(\cdot)$ is the standard normal CDF.

The last set of moment conditions are used to identify the parameters of the unobserved bid-preparation cost distribution. These moment conditions are

$$E\left[n_{mw}\right]=\int N_{mw}p_{mw}dF\left(\boldsymbol{x}_{w},\boldsymbol{z}_{w},N_{mw},N_{-mw}\right), \tag{6}$$

$$E\left[n_{mw}^{2}\right] = \int N_{mw}p_{mw}\left(1-p_{mw}\right)+N_{mw}^{2}p_{mw}^{2}dF\left(\boldsymbol{x}_{w},\boldsymbol{z}_{w},N_{mw},N_{-mw}\right), \tag{7}$$

$$\begin{aligned} E\left[n_{mw}^{3}\right] &= \int N_{mw}p_{mw}\Big(1-3p_{mw}+3N_{mw}p_{mw}+2p_{mw}^{2}-3N_{mw}p_{mw}^{2} \\ &+ N_{mw}^{2}p_{mw}^{2}\Big)dF\left(\boldsymbol{x}_{w},\boldsymbol{z}_{w},N_{mw},N_{-mw}\right), \end{aligned} \tag{8}$$

and

$$\begin{aligned} E\left[n_{mw}^{4}\right] &= \int N_{mw}p_{mw}\Big(1-7p_{mw}+7N_{mw}p_{mw}+12p_{mw}^{2}-18N_{nw}p_{mw}^{2}+6N_{mw}^{2}p_{mw}^{2} \\ &- 6p_{mw}^{3}+11N_{mw}p_{mw}^{3}-6N_{mw}^{2}p_{mw}^{3}+N_{mw}^{3}p_{mw}^{3}\Big)dF\left(\boldsymbol{x}_{w},\boldsymbol{z}_{w},N_{mw},N_{-mw}\right) \end{aligned} \tag{9}$$

where

$$p_{mw}=G_{k}^{m}\left(\Pi\left(\boldsymbol{x}_{w},N_{mw},N_{-mw}\right)\mid\boldsymbol{z}_{w}\right)$$

is the group-specific entry probability. These moment conditions are derived from the assumption that entry is dictated by a joint binomial distribution where the probabilities bidders assign to entry is consistent with the actual entry probabilities.

## 6.4 Parametric Identification

The focus of this paper is on affiliation, so it is useful to briefly discuss how the affiliation parameter is identified from the data[25]. In that light, there are two pathways through which I identify the affiliation

[25]To my knowledge, there are no general nonparametric identification results in models with endogenous entry and affiliated private vales. Absent these nonparametric results, I must rely on parametric assumptions for identification.

parameter. The first pathway is through the dependence of bids as measured by Kendall's tau. In other words, if the observed bids tend to be positively dependent conditional on the observables, then the model will attribute that dependence to the affiliation parameter. The second pathway is through the entry probabilities of firms, specifically through the computation of the ex-ante profits in the entry probabilities. These profits represent the expected benefit from entering the auction and are subject to change depending on the degree of affiliation in the auction. Changing the ex-ante profits will therefore change the entry probability of firms, aiding in the identification of the affiliation parameter.

# 7 Empirical Results

This section presents the empirical results from the NMDOT procurement data. I first show the summary summary statistics to highlight some of the main components of the data. I then present reduced-from evidence of how bidding and entry responds to changes in contract characteristics and residency status. Lastly, I present the structural parameter estimates from the empirical model. These parameter estimates suggest that project-completion costs are affiliated, and that residents have higher entry costs when compared to non-residents.

## 7.1 Summary Statistics

Table 1 contains the summary statistics on project size, number of bidders and number of planholders for all New Mexico procurement contracts in the sample.

Table 1: Summary Statistics for New Mexico Procurement Contracts ($n = 226$)

| | Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max. |
|---|---|---|---|---|---|---|
| Engineer's Estimate (in 1000s) | 78.91 | 672.50 | 1794.00 | 3448.00 | 4719.00 | 67740.00 |
| Working Days | 15.00 | 60.00 | 90.00 | 114.10 | 123.80 | 780.00 |
| Length (in miles) | 0.00 | 0.21 | 1.10 | 5.34 | 4.53 | 191.20 |
| Number of Licenses | 0.00 | 1.00 | 1.00 | 1.44 | 2.00 | 3.00 |
| Resident Plan Holders | 2.00 | 7.00 | 8.00 | 8.25 | 9.00 | 14.00 |
| Non-Resident Plan Holders | 0.00 | 1.00 | 1.00 | 1.61 | 2.00 | 6.00 |
| Resident Bidders | 0.00 | 2.00 | 2.00 | 2.65 | 3.00 | 7.00 |
| Non-Resident Bidders | 0.00 | 0.00 | 1.00 | 0.87 | 1.00 | 4.00 |

These contracts are large. On average, projects have an engineer's estimate of $\$3,448,000$ where the engineer's estimate is determined by the NMDOT to be a fair price for completing a construction contract and is used as a proxy for size. Working days are specified in the contract as the maximum number of days a vendor can take to complete a particular project. In other words, working days provides an upper bound on the time required to complete a project. The sample has a wide range of working days requirements, ranging from about one-half of a month to more than two years. Similarly, there is a wide range of project lengths in the sample. While the median project covers 1.10 miles of road, there are projects that are as long as 191.2 miles. Licensing requirements are also included in the table as a measure of project difficulty. While most projects require firms to have at least one license to bid, there are some projects that have no requirements and others require as many as three licenses. The average number of required licenses is 1.44. In terms of planholders, projects have an average of about 8 resident planholders and about 2 non-resident planholders. An average of about 3 resident and 1 non-resident vendor actually participates in the auction of the vendors who have planholder status.

Projects in the data can be funded by the state government and the federal government. Projects that only use state funds are classified as state-funded projects and are subject to the resident bid preference program. Conversely, projects using some type of federal funds are classified as federal aid projects and are not subject to the resident bid preference program. Tables 2 and 3 show the number of state-funded and federal aid projects in the sample and how these types of projects differ in terms of size, the number of resident and non-resident planholders, and the number of resident and non-resident actual bidders.

Table 2: Bidders and Planholders for Federal Aid Projects ($n = 211$)

| | Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max. |
|---|---|---|---|---|---|---|
| Engineer's Estimate (in 1000s) | 78.91 | 789.70 | 1929.00 | 3624.00 | 4810.00 | 67740.00 |
| Resident Holders | 2.00 | 7.00 | 8.00 | 8.27 | 10.00 | 14.00 |
| Non-Resident Holders | 0.00 | 1.00 | 2.00 | 1.67 | 2.00 | 6.00 |
| Resident Bidders | 0.00 | 2.00 | 2.00 | 2.59 | 3.00 | 7.00 |
| Non-Resident Bidders | 0.00 | 0.00 | 1.00 | 0.90 | 1.00 | 4.00 |

Table 3: Bidders and Planholders for State Projects ($n = 15$)

| | Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max. |
|---|---|---|---|---|---|---|
| Engineer's Estimate (in 1000s) | 96.94 | 466.50 | 620.30 | 979.70 | 1537.00 | 2791.00 |
| Resident Holders | 5.00 | 7.00 | 8.00 | 8.00 | 8.50 | 14.00 |
| Non-Resident Holders | 0.00 | 0.00 | 1.00 | 0.73 | 1.00 | 2.00 |
| Resident Bidders | 2.00 | 2.00 | 3.00 | 3.47 | 4.00 | 7.00 |
| Non-Resident Bidders | 0.00 | 0.00 | 0.00 | 0.40 | 1.00 | 2.00 |

One limitation of the data is that I do not observe a large number of state-funded contracts. This limitation partly motivates the need for an empirical model since the model characterizes how bidders would act in response to bid preferences using information from both auction formats. Concerning size, state-funded projects are, on average, 3.7 times smaller than federal aid projects. In terms of potential and actual bidders, more resident bidders enter state-funded projects compared to federal aid projects, but state-funded projects and federal aid projects have about the same number of resident planholders on average. Non-resident bidders make up a smaller number of planholders and actual bidders in state-funded projects compared to federal aid projects.

### 7.2 Reduced-Form Results

I begin my analysis of resident preferences by investigating the reduced-form effects of the preference program on submitted bids. Here it is important to note that the variation in federal aid contracts is used to identify bidding behavior in the absence of the bid preference program. Thus, a key identifying assumption in the reduced form is that the bid preference program is the only difference between a state-funded and federal aid project with the same observable characteristics when contractors decide to submit bids.

I model the log of the submitted bid as

$$\log\left(b_{iw}\right) = \beta_1 NM_w + \beta_2 NM_w \times RESIDENT_i + \psi' \mathbf{X}_{iw} + \lambda_i + \eta_i + \phi_i + \epsilon_{iw}$$

where $b_{iw}$ is the submitted bid for vendor $i$ in auction $w$, $NM_w$ is an indicator variable that takes on a value of one if the project is state-funded, $RESIDENT_i$ is an indicator variable that takes on a value of one if the bidder qualifies for resident preferences and $\mathbf{X}_{iw}$ is a vector of project characteristics which includes resident interaction terms. I also include $\lambda_i$ as a month fixed effect and $\eta_i$ as a year fixed effect to control for the seasonality of construction contracts and any unobserved year-to-year differences. Firm fixed effect $\phi_i$ is included to control for any possible firm level differences that I cannot observe from the data. The main parameter of interest in this specification is $\beta_2$; this parameter captures the difference in how resident and non-resident vendors bid in a preference auction holding all other observables and fixed effects constant.

Table 4 presents the estimates from the regression. The reduced-form results show that bidders with preferences do bid differently than bidders without preference in preference auctions. In particular, the effect of preferences on submitted bids is estimated to be large and statistically significant. Resident vendors bid about 24.8 percent higher than non-resident vendors on state-funded projects, suggesting that non-residents bid more aggressively conditional on entry.

Submitted bids also depend on the project characteristics specified in the contract. Projects that are given more working days to complete receive higher bids since these projects are expected to take longer to complete. Other factors that increase the submitted bid include the number of licenses required to complete the project, the length of the project, and the percentage of the project that is required to be completed by disadvantaged business enterprises (DBEs). Conversely, firms who submit bids on projects located in urban counties bid 11 percent less than firms who submit bids in rural counties, and this result is significant at the 5 percent level. This difference most likely comes from the lower cost associated with working in an urban area as opposed to a rural area. Similarly, projects located on federal highways such as I-10 and US 70 receive lower bids than projects on state roads and local intersections, but these results are not statistically significant.

The number of planholders, included as controls for unobserved project heterogeneity, and the number of actual bidders have different influences on the submitted bid. On one hand, the actual number of bidders reduces the submitted bid due to the increase in competition. Adding an additional resident bidder to the set of actual bidders results in a decrease in submitted bids of 1.95 percent, while adding an additional non-resident bidder results in a larger decrease of 4.13 percent. It is important to note that the negative and significant effect of the number of actual bidders on submitted bids suggests that firms are at least partially aware of the actual number of bidders when submitting bids. This observation is consistent with the modeling assumption that bidders observe the actual number of competitors prior to submitting bids. On the other hand, the number of planholders do not have a strong influence on the submitted bids. Given that these variables are used to control for unobserved project heterogeneity, the lack of an influence of planholders on submitted bids suggests that affiliation may outweigh unobserved project heterogeneity in this setting.

Another result that is important to consider is the heterogeneity between resident and non-resident bidders. This heterogeneity is captured by the interaction terms between residents and project characteristics. While most terms are either small or statistically insignificant, the length of the project is a major source of heterogeneity between the different groups of bidders. Resident vendors bid an additional 0.23 percent higher than non-residents per mile on these construction projects, showing that longer projects are more costly for residents. This increase in cost could be the result of the employment and residency restrictions required to qualify as a resident.

In order to analyze entry behavior, I estimate a probit regression as a model of a firm's entry decision. The dependent variable is the decision of a firm to enter an auction, and I include controls for project characteristics, controls for location, controls for month effects, and controls for year effects. The errors account for clustering at the project level. Table 5 shows the coefficients and marginal effects for some of the level terms.

The levels of the entry regression reveal that residents are 24 percent less likely to enter these procurement auctions and this effect is significant at the 1 percent level. The model provides two explanations for these

Table 4: OLS Regression on Bids

| | *Dependent variable:* |
|---|---|
| | log(Bid) |
| New Mexico Project | $-0.2637^{***}$ |
| | (0.0881) |
| log(Engineer's Estimate) | $0.9040^{***}$ |
| | (0.0181) |
| Working Days | $0.0004^{**}$ |
| | (0.0002) |
| Urban | $-0.1102^{**}$ |
| | (0.0463) |
| Number of Licenses Required | 0.0295 |
| | (0.0300) |
| Length (in miles) | $0.0022^{***}$ |
| | (0.0008) |
| DBE Goal (%) | $0.0221^{**}$ |
| | (0.0096) |
| Federal Highway | −0.0575 |
| | (0.0379) |
| Resident Planholders | −0.0046 |
| | (0.0076) |
| Non-Resident Planholders | 0.0111 |
| | (0.0119) |
| Resident Bidders | $-0.0195^{*}$ |
| | (0.0110) |
| Non-Resident Bidders | $-0.0413^{**}$ |
| | (0.0177) |
| Resident × NM Project | $0.2482^{**}$ |
| | (0.1012) |
| Resident × Working Days | 0.0002 |
| | (0.0001) |
| Resident × Urban | 0.0572 |
| | (0.0398) |
| Resident × Licenses | 0.0006 |
| | (0.0289) |
| Resident × Length | $0.0023^{**}$ |
| | (0.0010) |
| Resident × DBE | −0.0063 |
| | (0.0091) |
| Resident × Federal Highway | 0.0503 |
| | (0.0368) |
| Observations | 795 |
| Adjusted $R^2$ | 0.9758 |

*Note:* $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01
Controls for type of work and disrict as well as month, year and firm fixed effects are included. Errors are clustered at the project level.

lower resident entry rates: either residents have lower expected profits for participating in a project, or residents have higher bid preparation costs. Given that ex-ante profits and entry costs are not observed in the data, it is difficult to interpret the sign and significance of this parameter.

Table 5: Entry Logit

| | *Dependent variable:* | |
|---|---|---|
| | Entry | |
| | Coefficients | Marginal Effects |
| | (1) | (2) |
| log(Engineer's Estimate) | 0.0688 | 0.0260 |
| | (0.0454) | (0.0170) |
| New Mexico Project | −0.1314 | −0.0480 |
| | (0.3926) | (0.1380) |
| Resident Bidder | −0.6113*** | −0.2370*** |
| | (0.0768) | (0.0300) |
| Resident Planholders | 0.0016 | 0.0010 |
| | (0.0173) | (0.0060) |
| Non-Resident Planholders | −0.0495 | −0.0180 |
| | (0.0325) | (0.0120) |
| Observations | 2,229 | 2,229 |
| *Note:* | | *p<0.1; **p<0.05; ***p<0.01 |
| | Controls for project characteristics, month effects and year effects are included. Errors are clustered at the project level. | |

The levels of the other project characteristics are either small or statistically insignificant. In terms of the model this result again suggests that firms are determining entry by their bid-submission costs as opposed to the project characteristics since project characteristics are used to compute expected profits.

## 7.3 Structural Parameter Estimates

I now disentangle a firm's participation and bidding decisions using the empirical model outlined in section 6. In order to mitigate the effect of unobserved project heterogeneity on submitted bids, I use the number of potential entrants in each group in my set of control variables. The idea behind these controls is that unobservable project characteristics may attract more potential entrants which is reflected in the number of planholders for each project. I also use a rich set of project controls to ensure that the correlation in submitted bids is mainly generated through affiliation in costs as opposed to unobserved project characteristics that are common knowledge to the bidders. Table 6 contains the parameter estimates for the bid distribution.

The parameter estimates for the bid distribution have the expected signs and magnitudes. The resident parameter estimates imply that there are differences in the bidding behavior of resident and non-resident bidders. In particular, resident bidders have a higher average bid and a more disperse bid distribution com-

Table 6: Estimated Parameters for the Bid Distribution

| | Coefficient | Standard Error |
|---|---|---|
| Constant | 1.091 | 0.224 |
| Resident | -0.011 | 0.013 |
| New Mexico project | -0.048 | 0.086 |
| log(Engineer's Estimate) | 0.931 | 0.017 |
| Length (in miles) | 0.001 | 0.001 |
| Working Days | 0.0005 | 0.0002 |
| Resident Planholders | 0.006 | 0.008 |
| Non-Resident Planholders | 0.017 | 0.013 |
| Bridge Work | -0.090 | 0.050 |
| Road Work | -0.051 | 0.048 |
| Number of Licenses Required | 0.008 | 0.021 |
| Federal Highway | -0.029 | 0.031 |
| Urban | -0.068 | 0.033 |
| DBE Goal(%) | 0.020 | 0.008 |
| District 1 | 0.042 | 0.034 |
| District 2 | -0.002 | 0.047 |
| District 3 | -0.008 | 0.054 |
| District 4 | 0.058 | 0.042 |
| District 5 | 0.116 | 0.051 |
| Resident Bidders | -0.020 | 0.012 |
| Non-Resident Bidders | -0.055 | 0.021 |
| Standard Deviation of Bid Distribution | | |
| Constant | 1.872 | 0.616 |
| Resident | 0.415 | 0.208 |
| log(Engineer's Estimate) | -0.270 | 0.056 |
| Affiliation Parameter | | |
| Theta | 0.989 | 0.243 |

*Notes* : Standard deviation of the bid distribution is estimated as $\sigma = \exp(b_0 + b_1 resident + b_2 engineer)$ where *resident* is an indicator for being a resident bidder and *engineer* is the log of the enginner's estimate.

pared to non-residents[26], and this difference is statistically significant. Furthermore, the affiliation parameter is statistically significant which supports the claim that affiliation is present in these procurement auctions. These results are comparable to Li and Zhang (2013) who also find that affiliation is important in the entry and bidding behavior of bidders in timber sales auctions.

Table 7 presents the estimated parameters for the log-normal entry cost distribution. Similar to the parameters of the bid distribution, the entry parameters have the expected signs and magnitudes. The parameter estimates again imply differences among resident and non-resident costs of entry; residents have

[26]Recall that these parameter estimates are the mean and variance of the natural logarithm of bids. The mean of the actual distribution of bids is calculated as $\exp\left(\mu + \frac{\sigma^2}{2}\right)$ while the variance is $\left(\exp\left(\sigma^2\right) - 1\right)\exp\left(2\mu + \sigma^2\right)$ where $\mu$ is the mean of the natural logarithm of the bids and $\sigma$ is the standard deviation of the natural logarithm of the bids.

higher average entry costs compared to non-residents and more variation in these entry costs. The parameter estimates are consistent with the lower conversion rate of potential resident bidders into actual bidders relative to non-residents observed in the data. Also, the majority of the other entry parameters have high standard errors compared to the bid distribution parameters. As a result, many of these parameters are statistically insignificant.

Table 7: Estimated Parameters for the Entry Distribution

| | Coefficient | Standard Error |
|---|---|---|
| Constant | 0.624 | 1.013 |
| log(Engineer's Estimate) | 0.676 | 0.495 |
| Resident | 1.116 | 0.451 |
| Resident Planholders | 0.049 | 0.832 |
| Non-Resident Planholders | -0.090 | 0.808 |
| Standard Deviation of Entry Costs | | |
| Constant | 0.321 | 0.753 |
| Resident | -0.543 | 0.375 |

*Notes* : Standard deviation of the entry distribution is estimated as $\alpha = \exp(b_0 + b_1 resident)$ where *resident* is an indicator for being a resident bidder.

## 8 Counterfactual Analysis

This section contains counterfactual policy experiments using the structural parameter estimates from section 7.3. I first explore how bidders respond to different discount levels. Then, I examine how different levels of affiliation affects auction outcomes.

These counterfactuals are simulated using the empirical model for consistency between the estimated data generating process and the counterfactual auction outcomes. For each potential entrant, I draw bids from the bid distribution estimated from the data. These bids are then inverted using the GPV approximation to generate the corresponding costs, and those costs are used to determine ex-ante profits. Next, bid preparation costs are drawn from their estimated distribution and are used to determine entry. Finally, firms who enter submit bids according to the estimated bid distribution. I repeat this process for $2,500$ counterfactual auctions, interpolating the auction outcomes using cubic splines.

## 8.1 Alternative Discount Rates

The decision of increasing or decreasing the discount level is often a major policy debate. Although New Mexico offers a fixed 5 percent discount for its resident bidders, there are other states with preference programs that offer as much as a 15 percent discount on public procurement projects. These different discount levels have different implications for the participation and bidding behavior of firms, and I examine this change in behavior using the structural parameter estimates together with the empirical model. Recall that the goal of these resident preference programs is typically to increase the number of resident auction winners. Thus, a natural auction outcome to study is the fraction of resident auction winners. I also consider the average winning bid since cost is a major policy concern as well. Figure 2 displays the results of multiple auction simulations of a project containing the modal project characteristics of projects qualifying for preference in the data.

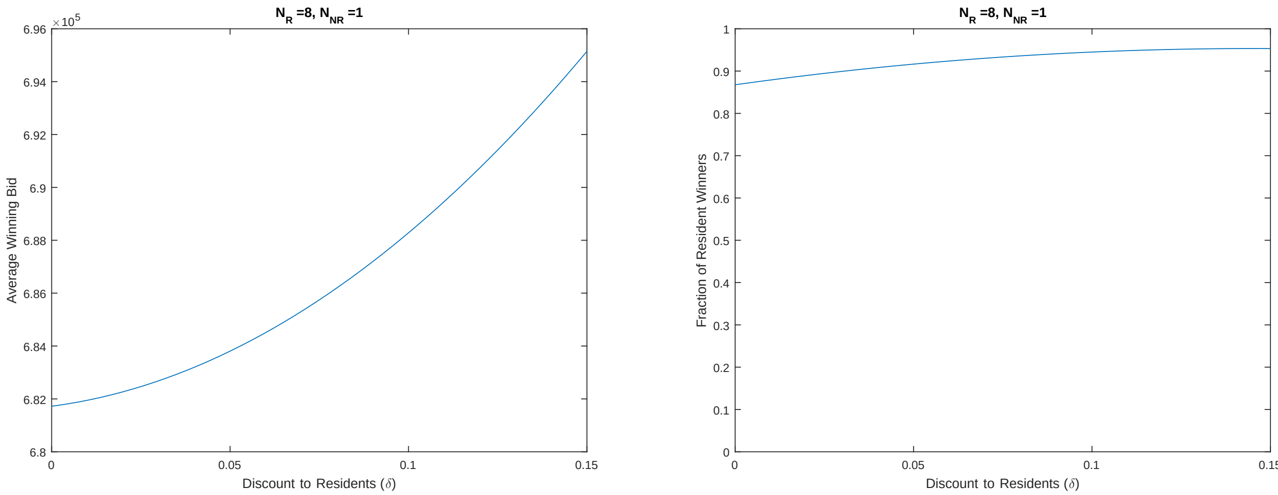


Figure 2: Average Winning Bid and Fraction of Resident Winners under Alternative Discount Rates

The policy simulations show that increasing the discount level increases the average procurement cost in these preference auctions; however, the increase in procurement cost is relatively small compared to the cost of the project. For example, increasing the discount rate from 0 percent to 15 percent only increases the average procurement cost of the modal construction project by around $\$14,000$ – a total increase of approximately 2 percent. The same increase in discount rate also increases the fraction of resident winners by about 0.15, suggesting that the NMDOT can increase the number of resident winners by increasing the resident discount rate without a substantial change in procurement costs.

## 8.2 Alternative Affiliation Levels

As demonstrated in section 2, project-completion cost affiliation also plays an important role in determining auction outcomes. As a result, I continue my counterfactual analysis of NMDOT preference auctions by considering the sensitivity of these auction outcomes to a range of different affiliation levels. These simulations are important if, say, the NMDOT offers a contract with an unusually high or low number of shared subcontractors or suppliers. These simulations are again centered around the modal preference auction in the data with the level of preference fixed at the current rate of 5 percent, and the results of these simulations are given in figure 3.

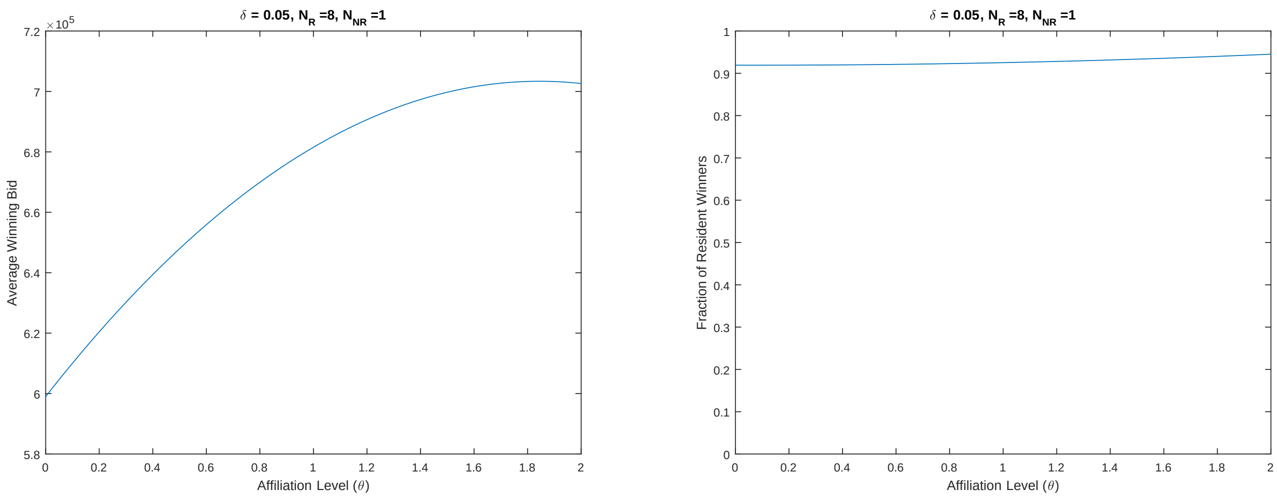


Figure 3: Average Winning Bid and Fraction of Resident Winners under Alternative Affiliation Levels

The simulations highlight two implications of project-completion cost affiliation. First, as project-completion costs become more affiliated, the average procurement cost to the government rises considerably. This change in procurement costs comes from less aggressive bidding by both types of bidders. Second, increasing project-completion cost affiliation does not have a large impact on the fraction of resident winners. The lack of a change in the fraction of resident winners is mostly explained through the small number of non-resident potential bidders and entrants in these preference auctions. The combination of these two results suggest that while affiliation is important in determining the final cost to the government, affiliation only has a small effect on the fraction of resident winning bidders.

# 9 Conclusion

This paper empirically examines the presence of affiliation and its effect on procurement auctions in an environment where the government offers bid discounts to a certain group of bidders. The focus of the analysis is on NMDOT construction contracts – a unique environment where resident bidders receive a 5 percent discount over non-resident bidders in construction contracts that use state funds. For the purpose of measuring affiliation and its effect on procurement, I develop a two-stage theoretical model where firms with potentially affiliated private project-completion costs first decide entry and then decide how much to bid. I empirically implement the theoretical model through the use of copulas, capturing affiliation through a tractable parametric restriction on the project-completion cost distribution. A reduced-form analysis on bids and entry decisions is then used to investigate any possible differences in bidding and entry behavior between resident and non-resident bidders, and the model is estimated via GMM to disentangle these two separate decisions.

The reduced-form analysis provides evidence for two distinct phenomena in NMDOT procurement auctions. First, non-resident bidders who enter a preference auction bid more aggressively than resident bidders. Specifically, I estimate that residents bid about 24.8 percent higher than non-residents on state-funded projects. Second, non-residents and residents bid and enter differently irrespective of whether the auction is a preference auction. I find that resident bidders are less likely to enter auctions and tend to bid less aggressively than their non-resident counterparts.

The structural analysis establishes the presence of affiliation and demonstrates the importance of affiliation in these procurement auctions. I find that the parameter that measures affiliation is positive and significant, indicating that vendors have affiliated project-completion costs. Counterfactual policy simulations reveal that affiliation is important in determining the cost of procurement but does not alter firm participation.

A number of open follow-up questions remain. Given that the focus of this study is on affiliation in project-completion costs, I abstract away from any dynamics in bidding strategies for tractability. Dynamics are potentially important since firms are typically constrained by the amount of projects they can complete, and firms may adjust bidding in response to having too many or too few awarded projects. Also, the complexity and focus of the model requires that I treat projects as single indivisible goods. In reality firms submit bids on all parts of the project simultaneously, suggesting that a scoring auction might provide additional insights on how firms determine their bids. These concluding observations lend themselves to future research.

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# A Approximating the Inverse Bid Functions with GPV in Auctions with Bid Preferences and Affiliation

The first order conditions in equation 1 can be rewritten as follows:

$$c_1 = b_1 - \frac{\boldsymbol{S}_1\left[1-F_c^{m_1}(c_1), 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), \ldots, 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), 1-F_c^{R}\left(\beta_{R}^{-1}\right), \ldots, 1-F_c^{R}\left(\beta_{R}^{-1}\right)\right]}{\frac{\partial \boldsymbol{S}_1\left[1-F_c^{m_1}(c_1), 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), \ldots, 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), 1-F_c^{R}\left(\beta_{R}^{-1}\right), \ldots, 1-F_c^{R}\left(\beta_{R}^{-1}\right)\right]}{\partial b_1}} \tag{10}$$

where

$$\begin{aligned}
&\frac{\partial \boldsymbol{S}_1\left[1-F_c^{m_1}(c_1), 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), \ldots, 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), 1-F_c^{R}\left(\beta_{R}^{-1}\right), \ldots, 1-F_c^{R}\left(\beta_{R}^{-1}\right)\right]}{\partial b_1} \\
= \; & (n_{NR} - D_{NR})\, \beta_{NR,1}^{-1} (1-\delta)^{D_R} f_c^{NR}\left(\beta_{NR}^{-1}\right) \\
& \times \boldsymbol{S}_{12}\left[1-F_c^{m_1}(c_1), 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), \ldots, 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), 1-F_c^{R}\left(\beta_{R}^{-1}\right), \ldots, 1-F_c^{R}\left(\beta_{R}^{-1}\right)\right] \\
& + (n_R - D_R)\, \beta_{R,1}^{-1} (1-\delta)^{-D_{NR}} f_c^{R}\left(\beta_{R}^{-1}\right) \\
& \times \boldsymbol{S}_{1n}\left[1-F_c^{m_1}(c_1), 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), \ldots, 1-F_c^{NR}\left(\beta_{NR}^{-1}\right), 1-F_c^{R}\left(\beta_{R}^{-1}\right), \ldots, 1-F_c^{R}\left(\beta_{R}^{-1}\right)\right].
\end{aligned}$$

Define $\tilde{b} = (1-\delta)^{D_R} b$ as the adjusted resident bid and $\hat{b} = (1-\delta)^{-D_{NR}} b$ as the adjusted non-resident bid. These adjusted bids are the bids from the competing group that the bidder calculating the optimal bid faces. Following the methodology outlined in GPV, the marginal CDF and PDF of costs can be expressed solely as functions of the bids by noting that

$$\begin{aligned} F_b^{NR}\left(\tilde{b}\right) &= F_c^{NR}\left(\beta_{NR}^{-1}\left(\tilde{b}\right)\right) \\ F_b^{R}\left(\hat{b}\right) &= F_c^{R}\left(\beta_{R}^{-1}\left(\hat{b}\right)\right) \end{aligned}$$

and

$$\begin{aligned} f_b^{NR}\left(\tilde{b}\right) &= f_c^{NR}\left(\beta_{NR}^{-1}\left(\tilde{b}\right)\right)\beta_{NR,1}^{-1}\left(\tilde{b}\right) \\ f_b^{R}\left(\hat{b}\right) &= f_c^{NR}\left(\beta_{R}^{-1}\left(\hat{b}\right)\right)\beta_{R,1}^{-1}\left(\hat{b}\right). \end{aligned}$$

Equation 10 can now be written as

$$c_1 = b_1 - \frac{\boldsymbol{S}_1\left[1-F_b^{m_1}\left(b_1\right), 1-F_b^{NR}\left(\tilde{b}\right), \ldots, 1-F_b^{NR}\left(\tilde{b}\right), 1-F_b^{R}\left(\hat{b}\right), \ldots, 1-F_b^{R}\left(\hat{b}\right)\right]}{\frac{\partial \boldsymbol{S}_1\left[1-F_b^{m_1}\left(b_1\right), 1-F_b^{NR}\left(\tilde{b}\right), \ldots, 1-F_b^{NR}\left(\tilde{b}\right), 1-F_b^{R}\left(\hat{b}\right), \ldots, 1-F_b^{R}\left(\hat{b}\right)\right]}{\partial b_1}}$$

which expresses costs as the sum of the bid and a strategic markdown.

# B Estimation Method

The parameters of the model are estimated via GMM which essentially matches the predictions of the empirical model to the moments of the data. This matching process requires assumptions on the bid distribution and bid-preparation cost distribution which were outlined in section 6.2. For completeness, these assumptions are given below:

$$\log\left(b_{iw}\right) = \boldsymbol{x}_{iw}'\beta + \epsilon_{iw}^{m_i}$$

$$\epsilon_{iw}^{m_i} \mid \boldsymbol{x}_{iw} \sim \mathcal{N}\left(0, \exp\left(\boldsymbol{x}_{iw}'\sigma\right)^2\right)$$

$$\left(\epsilon_{1w}^{NR}, \ldots, \epsilon_{n_{NR}w}^{NR}, \epsilon_{n_{NR}+1w}^{R}, \ldots, \epsilon_{n_{NR}+n_R w}^{R} \mid \boldsymbol{x}_{iw}\right) \equiv \boldsymbol{\epsilon}_w \sim F_{\boldsymbol{\epsilon}_w}$$

$$F_{\boldsymbol{\epsilon}_w} = \boldsymbol{C}\left[F_{\epsilon_{1w}^{NR}}, \ldots, F_{\epsilon_{n_{NR}w}^{NR}}, F_{\epsilon_{n_{NR+1}}^{R}}, \ldots, F_{\epsilon_{n_{NR}+n_R}^{R}}\right]$$

$$\log\left(k_{iw}\right) = \boldsymbol{z}_{iw}'\gamma + u_{iw}^{m_i}$$

$$u_{iw}^{m} \mid \boldsymbol{z}_{iw} \sim \mathcal{N}\left(0, \exp\left(\boldsymbol{z}_{iw}'\alpha\right)^2\right).$$

My first and second moment conditions are derived from the first and second moments of the bidding distribution:

$$E\left[\boldsymbol{x}_{iw}\left(\log\left(b_{iw}\right) - \boldsymbol{x}_{iw}'\beta\right)\right] = E\left[E\left[\boldsymbol{x}_{iw}\left(\log\left(b_{iw}\right) - \boldsymbol{x}_{iw}'\beta\right) \mid \boldsymbol{x}_{iw}\right]\right]$$

$$= E\left[\boldsymbol{x}_{iw}E\left[\left(\log\left(b_{iw}\right) - \boldsymbol{x}_{iw}'\beta\right) \mid \boldsymbol{x}_{iw}\right]\right] = E\left[\boldsymbol{x}_{iw}E\left[\epsilon_{iw} \mid \boldsymbol{x}_{iw}\right]\right] = 0$$

and

$$E\left[\boldsymbol{x}_{iw}\left(\log\left(b_{iw}\right) - \boldsymbol{x}_{iw}'\beta\right)\left(\log\left(b_{iw}\right) - \boldsymbol{x}_{iw}'\beta\right)\right] =$$

$$E\left[\boldsymbol{x}_{iw}E\left[\left(\log\left(b_{iw}\right) - \boldsymbol{x}_{iw}'\beta\right)\left(\log\left(b_{iw}\right) - \boldsymbol{x}_{iw}'\beta\right) \mid \boldsymbol{x}_{iw}\right]\right] =$$

$$E\left[\boldsymbol{x}_{iw}E\left[\epsilon_{iw}^2 \mid \boldsymbol{x}_{iw}\right]\right] = E\left[\boldsymbol{x}_{iw}\exp\left(\boldsymbol{x}_{iw}'\sigma\right)^2\right].$$

The corresponding empirical moments are

$$\frac{1}{W}\sum_{w=1}^{W}\frac{1}{n_{Rw}+n_{NRw}}\sum_{i=1}^{n_{Rw}+n_{NRw}}\left[\boldsymbol{x}_{iw}\left(\log\left(b_{iw}\right) - \boldsymbol{x}_{iw}'\beta\right)\right]$$

for the first moment and

$$\frac{1}{W}\sum_{w=1}^{W}\frac{1}{n_{Rw}+n_{NRw}}\sum_{i=1}^{n_{Rw}+n_{NRw}}\left[\boldsymbol{x}_{iw}\left(\log\left(b_{iw}\right)^2 - \left(\boldsymbol{x}_{iw}'\beta\right)^2 - \exp\left(\boldsymbol{x}_{iw}'\sigma\right)^2\right)\right]$$

for the second moment.

The next moment condition is derived from the equation for Kendall's tau for Clayton copulas. In particular, when the dependence between random variables can be modeled as a copula, Kendall's tau takes the following form:

$$\tau_{ij} = 4E\left[\boldsymbol{C}\left[F_u^i\left(u_i\right), F_u^j\left(u_j\right)\right]\right] - 1 \tag{11}$$

where $\tau_{ij}$ is Kendall's tau, and $u_i$ and $u_j$ are random variables that are related through the copula $\boldsymbol{C}[\cdot,\cdot]$ with marginal distributions $F_u^i$ and $F_u^j$ respectively. Given the assumption that the copula is a Clayton copula, the equation for Kendall's tau has a closed-form solution:

$$\tau_{ij} = \frac{\theta}{\theta + 2}. \tag{12}$$

Combining equations 11 and 12 gives the next moment condition which can be expressed as

$$\frac{\theta}{\theta+2} = 4E\left[\boldsymbol{C}\left[\Phi\left(\frac{\log(b_{iw}) - \boldsymbol{x}'_{iw}\beta}{\exp(\boldsymbol{x}'_{iw}\sigma)}\right), \Phi\left(\frac{\log(b_{jw}) - \boldsymbol{x}'_{jw}\beta}{\exp(\boldsymbol{x}'_{jw}\sigma)}\right)\right]\right] - 1 \quad i \neq j,$$

and the empirical counterpart for the above moment condition is

$$\frac{4}{W}\sum_{w=1}^{W}\frac{1}{\begin{pmatrix} n_{Rw} + n_{NRw} \\ 2 \end{pmatrix}}\sum_{1 \leq i < j \leq n_{Rw} + n_{NRw}} \boldsymbol{C}\left[\Phi\left(\frac{\log(b_{iw}) - \boldsymbol{x}'_{iw}\beta}{\exp(\boldsymbol{x}'_{iw}\sigma)}\right), \Phi\left(\frac{\log(b_{jw}) - \boldsymbol{x}'_{jw}\beta}{\exp(\boldsymbol{x}'_{jw}\sigma)}\right)\right]$$

$$-1 - \frac{\theta}{\theta+2}.$$

There is one subtlety in the above equation worth noting. The equation for $\tau_{ij}$ (equation 11) is given for copulas with two random variables, yet many auctions require that bids be drawn from copulas with three or more random variables. In response to this requirement, the above equation first takes averages over all combinations of pairs of bids in an auction then averages over all auctions to ensure that I use all of the information in the sample. In other words, for each auction I take the average Kendall's tau for each possible pair of bids and use that average when computing the empirical moment condition.

My final set of moment conditions are derived from the moments of the entry distribution. Given that entry is assumed to follow a binomial distribution, the first, second, third and fourth moments of the entry distribution given the number of potential entrants and project characteristics are

$$E\left[n_{mw} \mid \boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right] = N_{mw}p_{mw},$$

$$E\left[n_{mw}^2 \mid \boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right] = N_{mw}p_{mw}\left(1 - p_{mw}\right) + N_{mw}^2 p_{mw}^2,$$

$$E\left[n_{mw}^3 \mid \boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right] = N_{mw}p_{mw}\Big(1 - 3p_{mw} + 3N_{mw}p_{mw} + 2p_{mw}^2 - 3N_{mw}p_{mw}^2 + N_{mw}^2 p_{mw}^2\Big),$$

and

$$\begin{aligned} E\left[n_{mw}^4 \mid \boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right] &= N_{mw}p_{mw}\Big(1 - 7p_{mw} + 7N_{mw}p_{mw} + 12p_{mw}^2 - 18N_{nw}p_{mw}^2 + 6N_{mw}^2 p_{mw}^2 \\ &- 6p_{mw}^3 + 11N_{mw}p_{mw}^3 - 6N_{mw}^2 p_{mw}^3 + N_{mw}^3 p_{mw}^3\Big) \end{aligned}$$

respectively. Taking unconditional expectations over the number of potential entrants and the project characteristics yields the moment conditions described in section 6.3. These moment conditions are

$$E\left[n_{mw}\right] = \int N_{mw}p\left(\boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right) dF\left(\boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right),$$

$$\begin{aligned} E\left[n_{mw}^2\right] &= \int N_{mw}p\left(\boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right)\left(1 - p\left(\boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right)\right) \\ &+ N_{mw}^2 p\left(\boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right)^2 dF\left(\boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right), \end{aligned}$$

$$\begin{aligned} E\left[n_{mw}^3\right] &= \int N_{mw}p_{mw}\Big(1 - 3p_{mw} + 3N_{mw}p_{mw} + 2p_{mw}^2 - 3N_{mw}p_{mw}^2 \\ &+ N_{mw}^2 p_{mw}^2\Big) dF\left(\boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right), \end{aligned}$$

and

$$\begin{aligned} E\left[n_{mw}^4\right] &= \int N_{mw}p_{mw}\Big(1 - 7p_{mw} + 7N_{mw}p_{mw} + 12p_{mw}^2 - 18N_{nw}p_{mw}^2 + 6N_{mw}^2 p_{mw}^2 \\ &- 6p_{mw}^3 + 11N_{mw}p_{mw}^3 - 6N_{mw}^2 p_{mw}^3 + N_{mw}^3 p_{mw}^3\Big) dF\left(\boldsymbol{x}_w, \boldsymbol{z}_w, N_{mw}, N_{-mw}\right) \end{aligned}$$

The corresponding empirical moments are then given by

$$\frac{1}{W}\sum_{w=1}^{W}\left[n_{mw} - N_{mw}p_{mw}\right],$$

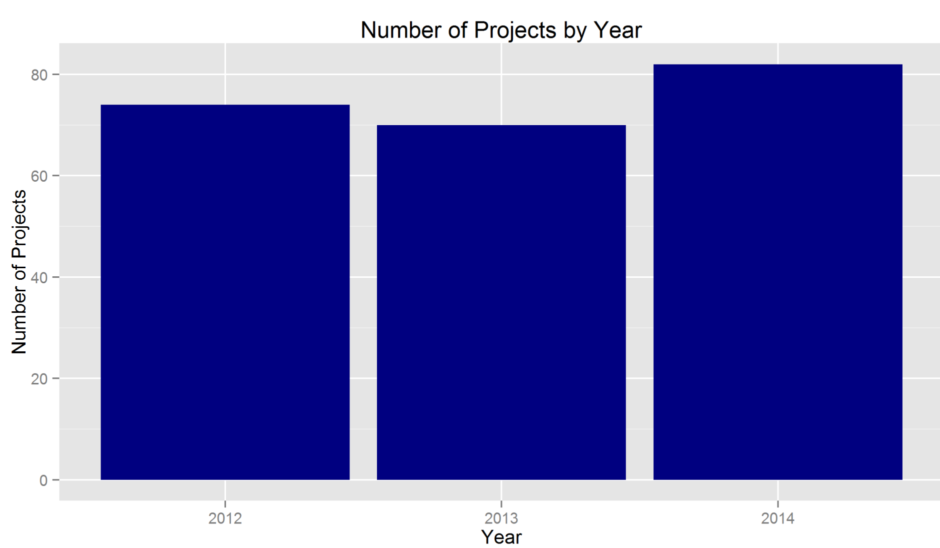
$$\frac{1}{W}\sum_{w=1}^{W}\Big[n_{mw}^2 - N_{mw}p_{mw}\left(1-p_{mw}\right) - N_{mw}^2 p_{mw}^2\Big],$$

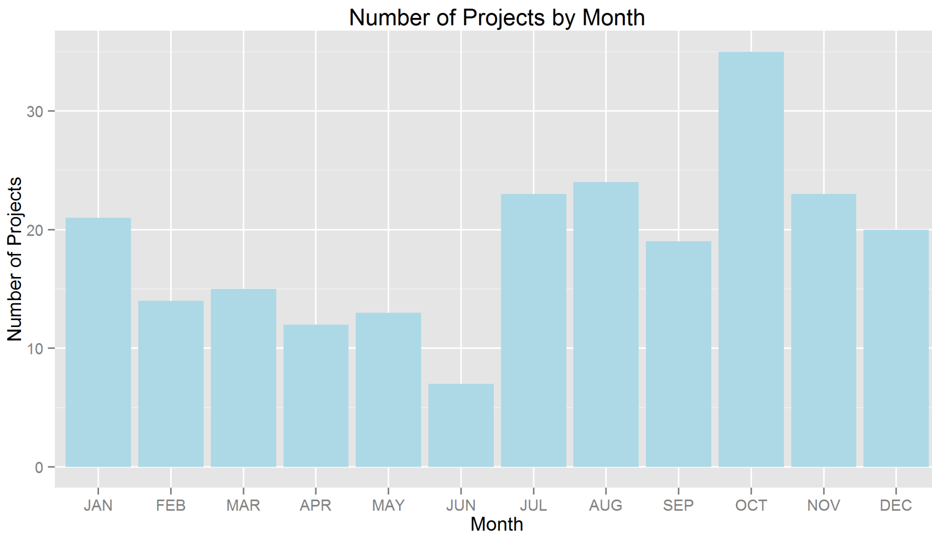
$$\frac{1}{W}\sum_{w=1}^{W}\Big[n_{mw}^3 - N_{mw}p_{mw}\Big(1 - 3p_{mw} + 3N_{mw}p_{mw} + 2p_{mw}^2 - 3N_{mw}p_{mw}^2 + N_{mw}^2 p_{mw}^2\Big)\Big],$$

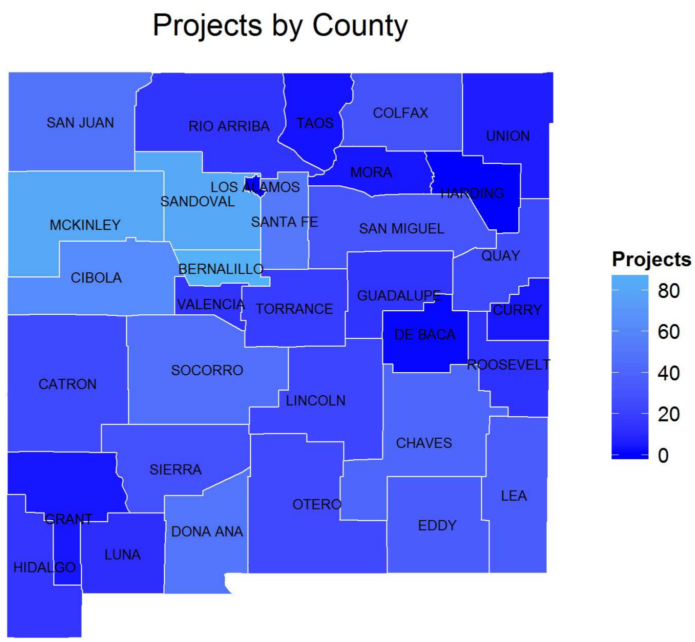
and

$$\begin{aligned}\frac{1}{W}\sum_{w=1}^{W}\Big[n_{mw}^4 \quad &- \quad N_{mw}p_{mw}\Big(1 - 7p_{mw} + 7N_{mw}p_{mw} + 12p_{mw}^2 - 18N_{nw}p_{mw}^2 + 6N_{mw}^2 p_{mw}^2 \\ &- \quad 6p_{mw}^3 + 11N_{mw}p_{mw}^3 - 6N_{mw}^2 p_{mw}^3 + N_{mw}^3 p_{mw}^3\Big)\Big]\end{aligned}$$

# C Additional Graphs, Charts, and Tables






Tables 8, 9, and 10 show the characteristics of the construction projects issued by the NMDOT. The majority of projects are related to bridge work or road work[27]. Also, about 60% of the projects take place

[27] I define bridge work as either bridge rehabilitation or bridge replacement, and I define road work as either roadway new construction, roadway reconstruction or roadway rehabilitation.

on a federal highway such as I-10 and US 70, while the remaining 40% take place on a different type of road which includes state roads and local intersections. Projects are more concentrated on rural roads as opposed to urban roads, but this trend is mainly due to the majority of the state being classified as rural.

Table 8: Project Types

| | Number of Projects |
|---:|---:|
| Bridge rehabilitation | 36 |
| Bridge replacement | 15 |
| Bridge replacement | 1 |
| Drainage improvements | 3 |
| Erosion control measures | 2 |
| Fencing | 1 |
| Intelligent transportation system | 1 |
| Lighting | 3 |
| Miscellaneous | 5 |
| Permanent signing | 1 |
| Ramp reconstruction | 2 |
| Ramp rehabilitation | 1 |
| Rest area | 1 |
| Roadway new construction | 6 |
| Roadway reconstruction | 31 |
| Roadway rehabilitation | 88 |
| Safety | 15 |
| Signalization | 6 |
| Stockpiling | 6 |
| Structures | 2 |

Table 9: Type of Road

| | Number of Projects |
|---|---:|
| Other Road | 91 |
| Federal Highway | 135 |

Table 10: Urban and Rural Project Locations

| | Number of Projects |
|---|---:|
| Rural | 132 |
| Urban | 94 |