Subcontracting Networks, Competition and Firm Participation in Public Procurement*

(Preliminary Draft)

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November 30, 2022

Abstract

In this paper, we study how networks of firms competing for government contracts are shaping access to subcontracting opportunities. Using Bayesian estimation methods, we analyze the dynamic effect of strategic link formation on bidding outcomes and market exit, controlling for bidder, auction, market characteristics and Disadvantaged Business Enterprise (DBE) participation goals. We employ thirteen years of data on all subcontracting activities from road construction auctions in Oklahoma and provide evidence that the network structure among contractors, particularly the non-DBE firms, is a critical factor impacting their choices and market presence. Ultimately, even for DBE firms, deeper networks established over time have helped the state government transition from race-conscious to race-neutral means of DBE support.

Keywords: Auctions; Subcontracting; Networks; Disadvantage Business Enterprise.

JEL Classification Codes: D44, D82, L14.

*This research was supported by NSF grant awards #1745604 and #1745605.

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1 Introduction

Network analysis is a growing area in economics research, recognizing that market participants are interdependent, and market outcomes are often shaped by complex, persistent interactions. In this paper, we take a closer look at market evolution in the road construction industry with special attention to subcontracting networks of small and disadvantaged business enterprises (DBE). In recent years, these firms experienced a significant decline in the use of race-conscious means to achieve DBE participation goals. The industry, overall, demonstrates a high degree of market concentration, where a handful of incumbents enjoy a significant market share while many firms compete on the fringes, struggling to make their market presence more than a short stint. Network analysis provides a new lens to study synergies, competition and market participation in the industry.

In public procurement, winning contractors often rely on subcontractors, to deliver parts of the awarded projects. As a result, significant business opportunities arise through access to a secondary subcontracting market. This access provides firms with another path to steady revenue and growth, especially for inexperienced and small firms that are most vulnerable to market fluctuations. Understanding the mechanics of subcontracting network formation is instrumental to a comprehensive industry study. A natural starting point in network analysis is to investigate the factors affecting the formation and evolution of network connections over time.[1] Our data analysis is based on a newly constructed data set of contracts and subcontracting activity from the Oklahoma Department of Transportation spanning thirteen years until 2016. It reveals that subcontracting is increasingly prevalent in road construction with 77.27% of contractors forming subcontracting relationships throughout the period and 81.21% of projects having at least one subcontract. This activity is steadily increasing through time with 57.24% of the projects having subcontracting engagements in 2004 and 87.47% in 2016.[2] It is, in fact, all too common for the winning contractor to hire more than one subcontractor, especially for large and complex projects. We examine how the depth and breadth of previous subcontracting engagement, the characteristics of firms and

[1] A network connection or link is formed when the winning contractor (the prime contractor or prime) hires another firm (the subcontractor) to perform certain tasks on the project.

[2] See Figure 1.

projects, and the similarity between firms may impact the formation of new connections and the maintenance of existing network links.

In this paper, we contribute to the empirical literature on networks by developing a framework of subcontracting choices. Our approach is most closely related to Christakis et al. (2020) who considered a sample of high school students and studied how the formation of a social network could affect class performance. By utilizing recent advances in econometric techniques originating in this work and further developed by He and Kosmopoulou (2021) in a study of the airline industry, we empirically analyze how a firm makes its decisions in forming links and how its market performance is impacted by those decisions. We also contribute to the literature on DBE participation and program efficiency (Marion, 2009, 2011; De Silva et al., 2012; Marion, 2017; Rosa, 2019) and build on the literature on outsourcing and subcontracting in the public procurement industry as it pertains to make-or-buy decisions, cost effectiveness (Gil and Marion, 2013; Miller, 2014; Marion, 2015; Branzoli and Decarolis, 2015; Moretti and Valponesi, 2015; Jeziorski and Krasnokutskaya, 2016; Rosa, 2020) and market participation (De Silva, Kosmopoulou and Lamarche, 2012, 2017).[3] Our paper extends these strands of the literature by considering the simultaneous outsourcing/subcontracting decisions of prime and subcontractors in the road construction market, based on project, bidder, auction characteristics and the relationships firms build dynamically within a network. Pairs of firms working together repeatedly, through contractual relationships, have the potential to coordinate complementary activities more efficiently and reduce transaction costs and time to completion. Those deepened relationships have implications for the market structure. In the outsourcing literature, Rosa (2020) simulates a Markov-Perfect equilibrium of an auction game with relationship dynamics and contrasts equilibria with and without affirmative action offering important insights. Our paper differs methodologically, brings in a networks dimension to subcontracting choices and through our empirical angle broadens the set of strategic considerations for building new links.

The rest of the paper is organized as follows. Section 2 provides background information about the relationships among prime contractors and subcontractors undertaking road construction. In Section 3, we describe our Bayesian estimation method and the empirical

[3]For an extensive review of this literature see Hortacsu and Perrigne (2021).

model. Section 4 describes how we construct the data and variables, and Section 5 presents the estimation results. In Section 6, we study the impacts of firms' subcontracting behaviors and those of the DBE program on firms' bidding outcomes and market participation. We conclude in Section 7.

2 Background on ODOT Procurement Auctions, Subcontracting and the DBE Program

The Oklahoma Department of Transportation (ODOT) holds monthly lettings to procure public construction work using a first price sealed bid auction format, where the lowest bidder is selected as the winner, representing the lowest cost to the state agency of completing a road construction project. Five weeks prior to the date of an ODOT letting, general information on projects scheduled for the following month is advertised to the public, while two weeks later interested contractors may request detailed plans of the projects from ODOT at a minimal cost.[4] Prior to the bid letting day, ODOT announces the identities of all firms who purchased plans, also known as "planholders". On the bid opening day, after the bids are submitted and reviewed, ODOT announces all bids, the winner and the identities of all other bidders.

A common practice for winning contractors who face competition from other bidders is to subcontract/outsource part of the work to other firms, thus creating a secondary subcontracting market for business opportunities and competition. Participation in this secondary market is beneficial for both contractors and subcontractors for several reasons. Contractors may outsource part of the work due to potential cost considerations, special needs, time constraints, risk allocation, and market competition. Subcontractors on the other hand, may benefit by undertaking business activity without the cost of bidding or going through the bid pre-qualification process. ODOT requires prime contractors to qualify before they are eligible to bid in its monthly lettings. Firms that qualify must meet certain threshold criteria in size (e.g. annual revenue and payroll). Firms that do not satisfy the requirements may

[4]This cost is usually less than 0.01% of the project's value, ranging from no cost to a thousand dollars

still participate in a project and bypass this scrutiny through the secondary subcontracting market. This may explain why prime contractors tend to be larger and more established firms, while subcontractors vary in size.

As we formalize and capture the subcontracting links, two subtleties need to be discussed in depth: 1) what counts as the formation of a subcontracting relationship, and 2) the timing of link formation. First, subcontracting is a formal relationship and can only be established by a project winner. However, not all connections between firms are formal. In a project, all bidders may establish informal connections with potential subcontractors at the stage of bid preparation. Nevertheless, an informal connection is transformed into a formal contractual relationship only after the project is procured and officially awarded to the winner. A formal contractual relationship (as opposed to an informal connection) allows the contractor and subcontractor to get to know each other better when they work together, interact and share more information. A formal contractual relationship offers subcontracting work experience, which matters more when firms look for business opportunities and make subcontracting decisions. Therefore, only a winner's formal contract with a subcontractor is counted as a formal subcontracting relationship rather than other losing bidders' informal connections. Second, although a formal subcontracting relationship is established only after the project is awarded, some informal connections are already made at the stage of bid preparation and thus a subcontracting relationship is decided when a firm prepares its bid. As a result, the characteristics of a potential subcontractor can affect whether the bidder is willing to establish a connection and if so, how much the bidder may decide to put forward in the bid. Likewise, the characteristics of a bidder can also affect the subcontractor's perception of the bidder's probability of winning the project and affect the likelihood that the subcontractor is willing to establish a connection with the bidder.

Subcontracting is also an important way for contractors to fulfill the requirements for the Disadvantaged Business Enterprise (DBE) Program. The DBE program is a federally funded program, designed to remedy potential discrimination against small businesses owned and controlled by socially and economically disadvantaged individuals (DBEs). ODOT imposes DBE goal requirements for some projects in its monthly lettings. A DBE project requires that a certain fraction of works must be undertaken by DBEs that participate in

the project as prime contractors, subcontractors, professional services, or Right-of-Way Service Providers. If the prime contractor is not a DBE firm but bids in a project with DBE goal requirements, subcontracting to a DBE firm can be an important way to fulfill the requirement, sometimes forcing firms to subcontract more than they otherwise would. One of the goals of our paper is to empirically evaluate the impact of networks on the DBE program (whose targeted support has gradually shifted from race-conscious to race-neutral means since Congress revised DBE regulations to comply with *Adarand v. Peña*) utilizing the rich information offered by measures of link formation.

3 The Model and Estimation Method

In the section, we discuss the empirical model and estimation method. Consider the F firms observed in our sample. There are P_{mt} projects in division m in period t and there are M divisions and T time periods in total. We describe firms' subcontracting networks by the adjacency link matrix. An adjacency link matrix $Link_{pmt}$ is an F by F matrix, whose elements depict the subcontracting status between each pair of firms in project p in division m in period t. We say that prime contractor i forms a link with subcontractor j if i wins the project in a letting and subcontracts part of it to j. Accordingly, we define $Link_{ijpmt} = 1$ $(i \in \{1, 2, ..., F\}, j \in \{1, 2, \ldots, F\}, i \neq j, p \in \{1, ..., P_{mt}\}, m \in \{1, 2, ..., M\}, t \in \{1, 2, ..., T\})$, where $Link_{ijpmt}$ is the ith and jth element of the link matrix $Link_{pmt}$. If i and j do not form a link, $Link_{ijpmt} = 0$. Since subcontracting is a directional relationship (i subcontracting to j and j subcontracting to i are different), the subcontracting networks between firms are directional as well. We define $Link_{iipmt} = 0$ since firm i cannot subcontract to itself. We also define $Link_t$ as the aggregation of $Link_{pmt}$ across all projects and divisions in period t.

A firm can undertake a project or choose to be a subcontractor in it. The firm can also decide to engage in neither activity. Naturally, not all firms are involved in each project, in each division or even in each period. To better capture all firms' subcontracting relationships, we use a 24-month moving window to track firms' most recent subcontracting network. Define $Network_t$ as an F by F matrix, whose ith and jth element $Network_{ijt} = max\{Link_{ijpmt} : i, j \in \{1, ..., F\}, p \in \{1, ..., P_{mt}\}, m \in \{1, ..., M\}, t \in \{t, t-1, ..., t-23\}\}$.

$Network_{t-1}$ indicates whether each pair of firms has formed a link in the previous 24 months. The variable $NetworkSum_{ijt-1}$ captures the number of links the pair has established within the same 24 month period representing the depth of interactions.

Following the Bayesian estimation method in Christakis et al. (2020) further developed by He and Kosmopoulou (2021), we allow each pair of candidate primes and subcontractors to decide if they will link in project p, in division m during period t. Since it is possible for a firm to be a bidder or a subcontractor, the candidate primes and subcontractors may include the same set of firms.

Define Π^1_{ijpmt} (Π^2_{ijpmt}) as the profit of a link formation for a candidate prime (subcontractor). Candidate prime i is willing to form a link with candidate subcontractor j in project p in division m in period t if $\Pi^1_{ijpmt} \geq 0$. Likewise, candidate subcontractor j will form a link with candidate prime i if $\Pi^2_{ijpmt} \geq 0$. We let k be an indicator for a potential prime ($k = 1$) or subcontractor ($k = 2$) and denote the profit function more concisely by Π^k_{ijpmt}. The profit function can be thought of from the traditional perspective as a function consisting of variables linked to revenues, R^k_{ijpmt} (or in this case the winning bid), material and labor costs, C^k_{ijpmt}, and transaction or coordination costs, τ^k_{ijpmt}, as follows:

$$\Pi^k_{ijpmt} = \alpha^k + R^k_{ijpmt} + C^k_{ijpmt} + \tau^k_{ijpmt} + \epsilon^k_{ijpmt}, \tag{1}$$

We construct our variables based upon networks formed across project types controlling for behaviors attributed to distinct risk sharing attitudes and cost sharing practices through fixed effects. In particular, α^k captures the various fixed effects including division, project type, bidder, potential subcontractor, and time fixed effect. The transaction or coordination costs measure costs associated directly with the formation of links but not directly with material and labor costs. They include variables affecting how profit is shared between prime contractors and subcontractors, the transaction cost from the negotiation between them, how well they meet each others' needs, and so on. To highlight our focus on subcontracting network formation, we re-group variables linked to the winning bid, material, labor and

coordination costs into a new set of categories leading to the following profit function

$$\Pi^k_{ijpmt} = \alpha^k + \beta^k_1 NetworkVar_{t-1} + \beta^k_2 X + \beta^k_3 \Psi + \beta_4 \omega_{t+1} + \epsilon^k_{ijpmt}. \tag{2}$$

$NetworkVar_{t-1}$ include variables that identify the breadth and depth of a firm's existing network. Some of these variables have a direct impact on the winning bid, such as the rivals' past links, and others are associated with coordination costs. X represents market level, project and firm characteristics that link to the winning bid and direct project costs. Ψ represents homophily measures that capture firm similarities. ω_{t+1} is a variable controlling for future business opportunities. More details on the correspondence between the variable groups in equation (1) and (2) are presented in Table A2 in the appendix.

Assume the error term ϵ^k_{ijpmt} follows a type I extreme value distribution. After taking the integral of ϵ^k_{ijmt}, the probability that a firm gains a non-negative profit and is willing to form a link satisfies the following equation

$$ln(\frac{Pr(\Pi^k_{ijpmt} \geq 0)}{1 - Pr(\Pi^k_{ijpmt} \geq 0)}) = \alpha^k + \beta^k_1 NetworkVar_{t-1} + \beta^k_2 X + \beta^k_3 \Psi + \beta_4 \omega_{t+1}. \tag{3}$$

A link forms only if both firms' profits are non-negative. Therefore, the probability of link formation is given by

$$P_{ijpmt} = Pr(Link_{ijpmt} = 1) = Pr(\Pi^1_{ijpmt} \geq 0) Pr(\Pi^2_{ijmt} \geq 0). \tag{4}$$

Denote β the parameter vector for α^k, β^k_i, $i = 1, ..., 4$ characterizing profits represented by Equation (2). Conditional on a given link matrix $Link$, the joint likelihood function is defined as

$$\mathcal{L}(\beta|Link) = \prod_{t \in \{25,...,T-11\}} \prod_{m \in \{1,...,M\}} \prod_{p \in Project_{mt}} \prod_{i \in I_{pmt}, j \in J_t, i \neq j} (P_{ijpmt})^{Link_{ijpmt}} (1 - P_{ijpmt})^{1 - Link_{ijpmt}}. \tag{5}$$

$Project_{mt}$ is the set containing all projects in division m in period t. I_{pmt} is the set of all candidate primes (bidders) in project p in division m in period t, and J_t is the set of

candidate subcontractors in period t. The set of candidate prime contractors include all firms that submitted a bid for the project. The set of candidate subcontractors consists of all bidders and subcontractors who were active in the market in the previous 24 and the following 12 months.[5]

Using the likelihood function in (5), we employ a Bayesian estimation method (Markov-Chain-Monte-Carlo) to estimate β.[6] After a large number of iterations, the distributions of the parameters will converge to their posterior distributions. We calculate the parameter means using the estimates from the last 500 iterations representing the posterior distributions and evaluate how significantly they differ from zero.[7]

4 Data and Variable Description

(i) Data Description. Project-level data are collected from monthly lettings held by ODOT. This publicly available information is matched with ODOT internal records on subcontracting to form the main dataset for our analysis. The data ranges from January 2004 to December 2016, spanning a thirteen-year window. Since ODOT does not hold lettings every month, our observations are collected over 143 months. During this time, 4348 projects are successfully auctioned off using the standard procurement process described in section 2, and 81.21% of them (3531 projects) employ subcontractors.

The bar plots in Figure 1 show the numbers of projects with and without subcontracting by year, type and location of projects and DBE requirements. Panel (1a) demonstrates how the number of projects changes during our sample period. It reveals an increasing trend

[5]The reasoning for this selection is that each firm that has been active around that period could potentially be a candidate subcontractor. The length of period used to consider active participants as candidates subcontractors is an empirical question. In an attempt to answer it, we aggregated our data at the project-firm level and run a logistic regression of current firms' subcontracting on their past and future market participation. We found that, the firms that were active in the past 24 months and became active in the future 12 months were significantly more likely to become subcontractors than other firms. The regression results are available upon request.

[6]The details can be found in the Appendix.

[7]The Bayesian approach unlike a probit or logit regression allows us to estimate the behaviors of prime contractors and subcontractors at the same time.

in the number of projects with subcontracting until 2010 (when the ARRA project infusion mostly occurred) but a decreasing trend in projects without subcontracting over time. Those trends level off after 2011 and until the end of the sample period. Panel (1b) compares the numbers of projects with and without subcontracting by type. Following ODOT practice, we recognize four basic categories of work: paving, bridge, grading and drainage (G&D) and traffic control. When a project involves two or more categories in its job description, we label its type of work as composite. As a result, the types of projects analysed include five mutually exclusive categories controlled for through project type fixed effects. A notable difference can be found in the total numbers of projects in these categories. The most frequently procured project types are Bridge and Paving while the least frequently procured type is G&D. The fraction of subcontracting projects varies across categories. Panel (1c) plots the numbers of projects by their locations. Eight geographical divisions are assigned by ODOT, where Division 4 (Oklahoma City Metro), Division 3 (Central Oklahoma, including the third largest county in the state, Cleveland County) and Division 8 (Tulsa Metro) account for the largest shares of projects, while Division 6 (Panhandle area) is where the least number of projects are located. The division map is provided in Figure 2. The fraction of subcontracting projects is slightly different across divisions reflecting variation in the type of projects undertaken. In order to control for division-specific impact on firms' subcontracting behavior and link formation, we add division fixed effects into our estimation. The last panel in Figure 1 (1d) plots project numbers by DBE status, identifying project DBE requirements. It shows that, less than a third of the projects have DBE requirements and in line with our expectations, DBE projects see a larger fraction of subcontracting. Our data also reveal that the DBE participation requirement in DBE project via race-conscious means has been decreasing steadily throughout the years from 6.7% of the winning bid amount in 2004 down to 3.3% in 2016. Those figures were much lower as a percentage of the value of all work completed and fell from 2.8% to 0.9% during the sample period. The value of DBE involvement across all projects on the other hand increased from 4.4% in 2004 to 10.1% in 2016 as shown in Figure 3. In our analysis, we include several dummy variables related to project and firm DBE status, thus estimating the DBE program's potential impacts on subcontracting and link formation and evaluating the effect on procurement costs of the state's increasing reliance

on race-neutral means to satisfy DBE goals.

Figure 4 presents the time series plots of four measures for projects with and without subcontracting: duration in days, complexity measured by the number of construction items in a work plan, dollar amount of the engineer's estimate, and dollar amount of the winning bid. There is no clear increasing or decreasing trend in project duration over time. There is an increasing trend in project complexity, engineering estimate and average winning bid in projects that involve subcontracting with no distinct trend in projects without subcontracting engagement. One clear pattern emerges from all four plots, namely, projects with subcontracting are considerably longer, more complex and have higher estimated costs, rendering a natural explanation for subcontracting needs. Engineering estimates and winning bids follow a very similar pattern over time leading to a similar relative winning bid ratios with the exception of 2009 and 2010 when most ARRA projects were procured.

Next, we consider only projects with subcontracting. Figure 5 plots the average winning bid and the average subcontracting amount for subcontracting projects over the years. While the winning bid amount exhibits an upward trend, the ratio of the subcontracted portion over the entire project in terms of dollar amount remains relatively stable over time. Although more projects are involving subcontractors over the years as shown in Figure (1a), this increasing popularity of subcontracting does not lead to a higher volume of subcontracting work within a project.

In Figure 6, we examine firms' subcontracting within a networks framework to visualize how the links evolve over time. Panel (6a) shows the subcontracting network in January 2006, the first period used in our model of estimation. In the figure, the nodes represent firms and the arrows represent firms' subcontracting links of the previous 24 months. The size of a node is proportional to the total number of links the firm has formed during this period, and the direction of an arrow indicates that the link points from a prime contractor to a subcontractor. We can see that a few nodes at the center have many links while many small nodes at the periphery have only one link. A dark grey node indicates that the firm serves mainly as a prime contractor in the network while a light gray node indicates that it serves as a subcontractor.[8] The total number of firms observed in our data is 962, but

[8]A dark grey node indicates that the firm participates in more projects as a prime contractor than as

only 887 firms participate in the formation of the network. The rest of the firms only bid but without winning a project and thus never form a link. During our sample period, 220 firms have served as prime contractors, and 815 firms have worked as subcontractors. There is considerable overlap between the two groups. Specifically, 148 firms have undertaken the roles of both prime and subcontractors, equivalent to 67% of all primes and 18% of all subs. Panels (6a), (6c) and (6e) present snapshots of the firms' 24 month prior subcontracting networks spread evenly across time. The numbers of nodes and links increase from 2006 to 2011, a period that includes the ARRA infusion of projects. The network becomes more and more dense as subcontracting becomes increasingly popular among firms. This network structure is maintained to a large extent even after the ARRA funds are exhausted and until the end of our sample period. Almost all nodes are connected within one main network. However, a separated small network may appear for a short period of time here and there. While small firms at the periphery have intermittent presence, most large firms at the center of the network have a constant presence indicating their strong market involvement. There are, however, exceptions in that even some large firms enter or exit the subcontracting market in the middle of our sample period. Panels (6b), (6d) and (6f) provide visualization of the DBE networks across time marked in blue. Panel (6b) reveals that the ARRA projects have provided opportunities for DBE firms to expand their network relative to 2006 and created synergies that lasted until the end of our sample period. This is despite the State's shift away from race conscious means of satisfying participation requirements that could have had implications on the range of projects DBE firms are involved in. All this variation in firms' subcontracting relationships through time provides us with an opportunity to investigate the formation and maintenance of firms' subcontracting networks.

Table 1 presents the summary statistics of the variables constructed at different levels in our sample. The project-level variables indicate that a typical project has about 6.5 planholders, 3.8 bidders, lasts 128.5 days, is worth around 2.4 million dollars, involves 45.7 work items and has a 30% chance to be a DBE project. The prime contractor in a typical project hires 3.7 subcontractors on average. On one extreme, the smallest projects may have 1 item or task to be completed, may receive only 1 bid, last 5 days and be worth as

subcontractor.

little as 12.6 thousand dollars. On the other extreme, the largest projects may involve 616 work items and cost up to 96.5 million dollars, they may have up to 11 bidders and last more than 3 years. As many as 22 subcontractors are observed to be working on a single project. The summary statistics of the firm-level variable $FirmDBE_{i(j)}$ indicate that about 7% out of 962 firms are DBEs. The average backlog for firms is \$372 thousand with the highest backlog commitment at \$117.2 million. We also measure the $DegreeCentrality_{i(j)t}$ as the number of links a firm has over a 24-month moving window, which captures the firm's importance in the network. On average, a firm has 2.5 links while at a maximum, a prime may have 257 links and a sub may have 342 links. $SubAmount_{i(j)t}$ is the prime contractor i's (subcontractor j's) subcontracting amount over a 24-month moving window. A firm has on average a subcontracting commitment of 419 thousand dollars. At maximum, a prime contractor subcontracts out works estimated at 88 million dollars while a subcontractor receives 39.6 million dollars in subcontracts.[9]

A prime who also serves as subcontractor tends to engage in subcontracting activity with both higher frequency and intensity than an exclusive prime, outsourcing 22.2 projects on average during our sample period with over \$17 million in subcontracting total for a firm, compared to 3.3 projects totaling \$1.3 million from the latter group. Comparison between subcontractors and subcontractors who serve also as primes demonstrates a similar pattern, with the latter group participating more frequently and registering higher subcontracting volumes. It is not clear, however, in which direction the cross-over between the two types of contractors takes place. That is, the question remains of whether established primes begin to take on horizontal subcontracting opportunities, or the secondary market serves as a springboard, elevating successful subcontractors to the primary market competition.

Geographical proximity between a prime and its subcontractor may influence the formation of relationship. As Table 2 shows, our sample consists of 220 prime contractors coming from 20 states, as far as Washington in the Northwest and Florida in the Southeast. 129 or 58.6% are based locally in Oklahoma, 19 are from the neighboring state of Kansas, 9 from Texas and 9 from Missouri, 13 are located in Florida and 6 are headquartered in Ohio. The

[9]We include the logarithm of $SubAmount_{i(j),t}$ in our estimation and as such set $SubAmount$ = \$1 instead of \$0 if a firm has no subcontracting activity.

remaining 14 states are contributing 35 firms combined. When we consider participation intensity, the distribution is significantly more skewed toward local contractors. Firms from Oklahoma are the primes for 12,770 out of 15,490 subcontracts, equivalent to 82.44% of the total subcontracting activity. Primes from Kansas outsource 1404 jobs through subcontracts or 9.06% of the subcontracting activity, and firms from all other states combined generate the remaining 8.49% of the total activity. In comparison, subcontractors are spread across 33 states as shown in Table 3. A similar geographic pattern of locations emerges, where Oklahoma based firms account for 64.8% of all subcontractors and 87.81% of all activity. Texas, Kansas and Arkansas are second, third and forth in both measures, and the other states each have under 1% of the number of subcontracts. Bearing in mind the overall geographic distribution, we turn to the relative location of linked primes and subs. A prime and its subcontractors are based in the same state 75.3% of the time, primarily attributable to the fact that over 85% of subcontracting volume goes to Oklahoma firms. Nevertheless, an out-of-state sub is 6.5 times as likely to be hired by an OK prime than a prime from their own state. When both prime and sub-contractors are located in Oklahoma, 36.3% of the time they are in the same district, 18.1% of the time they are based in the same county (out of 77 counties), and 17.6% of the time they are located in neighboring counties. All these numbers suggest that closeness in locations is a favorable condition for subcontracting links to be formed between firms.

(ii) Variable Description. The independent variables used in the analysis that follows can be classified into five main groups— variables related to network formation, project characteristics, bidder and rival characteristics, variables identifying homophily, and a variable capturing future business opportunities.

The variables grouped under $NetworkVar_{t-1}$ signify the connectivity of firms and their centrality in the network that can help us understand the impact of past relationships on the dynamics of network formation. In assessing the likelihood of a pair of firms establishing a subcontracting connection, we consider other connections that have been established in the past between these two firms and outside of their potential new relationship. Two informative constructs revealing the structure and strength of the subcontracting network are measured by hub and authority centralities. Hub Centrality and authority centrality,

both normalized to [0, 1], measure a firm's subcontracting links, and assign different weights to those links according to the importance of the firm it's been linked to (captured by the number of subcontracting connections). A high hub centrality value points to many significant subcontracting partners with critical value to the subcontracting network. A high authority value signifies that a firm is subcontracted to by many prime contractors with a large number of established links.

At the project level we include the number of planholders, the engineering cost estimate, the calendar days to complete a project and the number of items within the project. We also identify projects with DBE subcontracting goals and firms that qualify as DBE's. The number of planholders controls for differences in competition that might expand the possible subcontracting options and the likelihood of success. The calendar days to complete the project and number of items are provided by ODOT in the plan and are measures of project complexity. We include three variables that measure the cost heterogeneity of firms — the firm's backlog, the total amount of subcontracting activity in the past 24 months, and the firm's distance to a project. We also utilize past information on rivals' subcontracting connections controlling for rival cost heterogeneity. This is a measure of rival experience and success in forming subcontracting relationships. Rival characteristics affect directly the level of market competition and the price.

We include two variables to highlight similarities (homophliy) creating the potential for complementarities among firms. One is measuring the physical distance between two firms and the other the similarity in workload distribution across different project types.

Finally, we include a variable that controls for future opportunities in road construction, namely the real value of projects to be procured in the same division in the following month. It represents forward looking considerations in establishing a current link within the same division. Table A1 in the Appendix provides a detailed definition for each of the variables used in the study.

5 Estimation Results

In this section, we estimate simultaneously the prime contractors' (bidders') and subcontractors' probability of forming a contractual relationship. We consider four variations of the model described in Section 3. In the first one, we include all projects, incorporating the make or buy decision of the contractors and, in the second we consider all contracts that engaged in subcontracting to focus on the choices made among firms. In the third and fourth models, we estimate the same specifications using a linearly discounted network to acknowledge that recent network connections could be more salient in decision making.

Table 4 presents the means of the posterior distributions of the parameters and in parenthesis the probability that a parameter has the opposite sign of its mean. The lower probability signifies a higher likelihood that the mean is different from zero. Each model estimates bidders' and potential subcontractors' behaviors at the same time—the results in the first column explains the probability of a bidder subcontracting out part of the project while those in the second column explains the probability of a potential subcontractor being subcontracted with.

The first couple of rows present coefficient estimates capturing the impact of a firm's previous network structure on current link formation. The variables $Network_{ij,t-1}$ and $NetworkSum_{ij,t-1}$ measure the existence of network connections between contractor i and subcontractor j in the past 24 months and the strength of those connections. They provide evidence that past network ties exert strong influence on the current decision to reconnect. Familiarity and trust are essential to subcontracting business. Of all firms under consideration, prime contractors rely less on one single interaction to inform upcoming decisions and more on the entire history of past contractual engagements. A network turns out to be a less significant factor for a DBE subcontractor's likelihood to connect to primes. This is consistent with the goals of the DBE program in providing opportunities for engagement that would be independent of prior contracting experiences and deep network connections. The following ten rows represent measures of physical distance between contractors and distance from a contractor to the project location. The estimates reveal a complex multidimensional spacial impact that is characterized by significant nonlinear direct effects of firm distance

to project locations and considerations of relative distance between firms. Besides including physical distance, we consider another homophily measure, the $MetricDistance_{ij,t-1}$. This is the distance between the potential prime contractor i's and potential subcontractor j's workload distributions across different work types in the previous 24 months. The results show that $MetricDistance_{ij,t-1}$ has a varied effect on the prime's decision to subcontract out. A prime contractor may outsource work based on complementarities in specialization or work that it cannot perform in house due to multiple commitment. A subcontractor always seeks to engage in projects they have familiarity with. $DegreeCentrality_{i,t-1}$, a bidder's link number in the network of the last 24 months, has a negative impact on the likelihood to establish new links. Contractors are reluctant to expand an already broad network and subcontractors are reluctant to seek new connections with highly connected primes. This is also reflected in the estimate of $log(SubAmount)_{i,t-1}$, the dollar amount of the work that a bidder subcontracts out in the last 24 months. $log(SubAmount)_{i,t-1}$ decreases the likelihood of subcontracting for both prime and subcontractors.[10] On the other hand, $DegreeCentrality_{j,t-1}$, a potential subcontractor's link number in the network of the last 24 months has a positive influence on the decision to establish new links for prime contractors engaging with DBE subs. The reputation of well connected DBE subcontractors could generate new interest from prime contractors. $log(SubAmount)_{j,t-1}$, the dollar amount of the work that a subcontractor has accepted from prime contractors in the last 24 months, decreases the likelihood of creating a link for subcontractors. Subcontractors seem reluctant to over-commit capacity as very connected subs ultimately face capacity constraints.

Backlog, a measure of work commitment that assumes a constant completion rate over time, has a significant nonlinear impact on the decision to form a link. Conditional on degree centrality, subcontracting amounts and work complexity, larger primes tend to subcontract more than smaller primes. Similarly, subcontractors have an interest in connecting to large contractors with significant work commitments. Likewise, the backlog of subcontractors has a nonlinear impact on the decision of a contractor to form a link.

[10]Contractors that have already engaged in significant subcontracting business in the last 24 months, may prefer to do additional work in-house instead of outsourcing tasks. Subcontractors seek contractors who have not already committed a large part of their workload.

Conditional on controlling for degree centrality (the number of links of a contractor), neither hub centrality (capturing the relative importance of a prime contractor in the network compared to other prime contractors) nor authority centrality (measuring the relative importance of subcontractors in terms of the links established in the past 24 months by the primes they are connected to) have significant impact on the likelihood to create a new connection. The estimate of $RivalLink_{ijt-1}$ suggests that if a firm's rivals have formed many links in the previous 24 months, the firm (competing for the same pool of subs as its rivals) is less likely to form a link in the current period with any sub.

To investigate the impact of DBE participation goals on subcontracting choices we include a dummy variable that indicates whether the project has DBE requirements ($ProjectDBE_{pmt}$) and interaction terms between the project DBE dummy and the bidder/subcontractor DBE dummy ($BidderDBE_i/SubDBE_j$). We find that while DBE primes tend to subcontract less in DBE projects, reaching DBE participation goals often necessitates increases in the prime contractor's overall subcontracting behaviors. While this is desirable and consistent with the program's designed goals of broadening participation it opens the door to inefficiencies, manifested in higher costs to the state, something we investigate in the next section. DBE participation goals have forged synergies between non-DBE primes and DBE subcontractors offering opportunities for steady revenue and growth to those businesses. In the next section, we also attempt to speak to the impact of the gradual reliance on race neutral means to satisfy participation goals on state outlays.

Next, we look at project-level variables starting with those representing project complexity. Estimates of $Cdays$—calendar days of the project— and $ItemNumber$—the number of items in the project— indicate a positive impact on the likelihood to establish a connection. More complex project should require more firms with different specializations and more subcontracting from the prime contractor.

Finally, we consider a variable representing the real value of projects procured in the time period following the auction under consideration. The variable $ProjectValue_{m,t+1}$ shows mixed effects. While contractors seek to increase their network in the presence of future opportunities, subcontractors hold off in anticipation of future options.

6 Impacts on Firms' Bidding and Longevity

In this section, we investigate the impact of subcontracting and DBE designation on winning bids and firm exit from the Oklahoma market. First, we run a simple linear regression of the following specification,

$$log(WinBid_{pmt}) = \gamma_0 + \gamma_1 DegreeCentrality_{it-1} + \gamma_2 S + \gamma_3 X^* + \gamma_4 \Omega + \alpha_p + \nu_m + \epsilon_{pmt} \quad (6)$$

where the dependent variable is the log of the winning bid, for project p in division m at time t. Network effects for the winning bidder are captured in $DegreeCentrality_{i,t-1}$. S accounts for subcontracting activity expressed in amounts, percentages, number of items subcontracted out or number of subcontractors across five specifications. X^* represents market level characteristics, project characteristics and firm characteristics. Since our analysis of bids is at the auction level, we introduce additional variables related to auction, bidder and rival characteristics within auctions. Control variables related to auction characteristics include the number of bidders and DBE project allocation requirements. We control for prime and sub DBEs and for in-state and out-of-state prime firms. We also include the rivals' minimum backlog. Changes in the business environment are introduced in Ω using three variables: (1) the monthly unemployment rate, (2) the monthly building permits across the state, and (3) the real value of projects to be procured in the same division in the following month. Finally, α_p and ν_m represent project type and division fixed-effects, and ϵ_{pmt} denotes the error term.

Table 5 provides summary statistics for the regression variables and Table 6 shows the estimation results. In this part of the analysis, we focus on projects won by bidders who vary their subcontracting practices and drop projects undertaken by firms that either always engage subcontractors or never subcontract out part of their work. The results are robust to the inclusion of these observations but we chose to highlight the impact of variation in subcontracting upon the winning bids within firms. The first three columns in Table 6 indicate that subcontracting has a positive non-linear impact on prices, imposing premiums that diminish with the size of the project, leading to potential cost savings for large contracts. Columns (4)-(6) confirm the nonlinear relationship between subcontracting

and bidding outcomes across a number of considerations. We find that, the winning bid first increases with project size, subcontracting percentage, subcontracting item numbers or subcontractor numbers and after a certain range it decreases across all these dimensions.

Table 6 also shows estimation results related to the impact of DBE designation on winning bids. We find evidence that DBE prime contractors win with lower average winning bids across all projects relative to non-DBE firms. When it comes to DBE projects though, DBE primes bid relatively less aggressively, closing the gap in bidding between DBE primes and other contractors. Firms engaging DBE subcontractors submit slightly less competitive bids across all projects (a result that is statistically significant in two out of the six specifications) but more competitive bids in DBE projects. At the end of Table 6, we make a direct comparison of DBE firms' behaviors in DBE projects with that of non-DBE primes. DBE primes submit higher bids in DBE projects on average but the p-value in the joint F test indicates that the results are not statistically significant. This behavior does not change over time. On the other hand, on average, the bids in DBE projects with DBE subcontractors are more aggressive than the bids in other projects. This differential behavior has been decreasing over time. As the range of projects that are designated as DBE is limited over time in compliance with the regulation that requires a gradual shift to race-neutral means of satisfying the DBE participation goals, the winning bids for DBE projects with DBE subcontractors are becoming higher.

With regard to other auction related variables in the model, the engineering cost estimate, the number of bidders, the calendar days of a project and the number of items in a project appear to have the most consistent impacts. As the number of bidders increases, bidding becomes more aggressive and winning bids fall. The calendar days and the number of item are measures of complexity with higher numbers signifying more complex projects that are typically associated with higher winning bids. At the bidder level, degree centrality and the rival's minimum backlog are the most impactful controls. Conditional on the level of subcontracting engagement in a project, the more varied the past connections have been the higher the level of the winning bid. The backlog of rivals on the other hand, signifying the size of the competitor, has a consistent competitive impact on the price. Finally, unemployment, a variable capturing the state of the economy has negative effect across specifications. The

higher the unemployment, the more competitive bidding becomes among firms that have fewer outside options for business activity.

Table 8 presents the logistic regression estimation results regarding the impact of subcontracting and DBE designation on firms' market participation based on the following model of the probability of exit for firm i in period t

$$ln(\frac{Pr(exit_{it})}{(1-Pr(exit_{it})}) = \eta_0 + \eta_1 NetworkVar + \eta_2 \mathcal{X} + \eta_3 \Omega^*. \quad (7)$$

The data is aggregated at firm-month level. The variable $exit_{it}$ is a dummy indicating a firm's exit from the Oklahoma road construction market. This variable is equal to 1 if a firm has no work in progress with ODOT for the following 24 months and until the end of the sample period either as prime contractor or as subcontractor.[11] While in columns (1) and (2) we used all data until the end of the sample period, in columns (3) and (4), the last 24 months were dropped for consistency in the definition of exit, since we don't have alternative sources of information to verify market exit beyond 2016. $NetworkVar$ are network variables, representing the degree centrality measures for prime contractors ($DegreeCentrality_i$) and subcontractors ($DegreeCentrality_j$). $\mathcal{X}$ include firm characteristics and Ω^* market-level characteristics. Market characteristics are reflected in $Unemployment$ and $log(BuildingPermit)$. Firm characteristics include $Instate$, $Prime$, Sub, and indicators of firm participation in DBE projects.

The estimation results show that participating in a project as either the prime contractor or a subcontractor decreases a firm's probability of exit, indicated by the significant estimates of the $Prime$ and Sub, and the indicator of engagement as both prime and subcontractor in the market during that period ($Prime \times Sub$).

We find that DBE firms have lower probability of exit. Moreover, participating in a DBE project either as a prime contractor or subcontractor decreases a firm's probability of exiting the Oklahoma market with more pronounced effects for those doing subcontracting work.

An increase in state unemployment increases the probability of market exit as more firms

[11]The estimation results are robust to a change in the definition of $exit_{it}$ to reflect no work in the following 36 months instead of 24.

compete in this market reducing the likelihood of an award. An increase in the number of building permits in the past year, on the other hand, increases the probability of exit as there are competing outside options. More importantly, networks play a significant role in maintaining market presence. The degree centrality is most significant on the subcontractor's side. This variable measures the distinct number of contractors a firm has done subcontracting work with and confirms our expectation that networks provide much needed support to fringe firms looking for business opportunities through the secondary market.

7 Conclusion

In this paper, we study the formation of networks connecting firms through subcontracting relationships in the Oklahoma road construction industry. We find that firms' previous connections have a notable impact on their subcontracting decisions and affect their chances to maintain presence in the market. We empirically confirm that the DBE program has led to an increase in subcontracting behaviors, helping DBE subcontractors stay active in business. Thanks to the program, DBE firms did not have to rely on deep network connections to secure jobs. Nevertheless, the network connections established through time, have allowed the Oklahoma Department of Transportation to shift more rapidly its percentage commitment to DBE participation from race-conscious to race-neutral means that are broadly considered more efficient.

We also study the impact of subcontracting and the DBE program on firms' bidding outcomes. The result offer strong evidence that subcontracting has a nonlinear effect on winning bids. Large complex projects benefit from subcontracting the most, leading to lower costs for the state. While overall, projects engaging DBE firms as prime contractors have lower winning bids, the gap is closing for projects with significant DBE participation goals led by DBE primes, underlying the effects of limiting competition. DBE subcontractors have a competitive impact only on DBE projects. Overall, the networks that have been developed through time have helped enhance participation of Disadvantaged Business Enterprises despite diminished targeted programmatic support. Networks have contributed to the development the familiarity and trust that are important in maintaining successful business

relationships.

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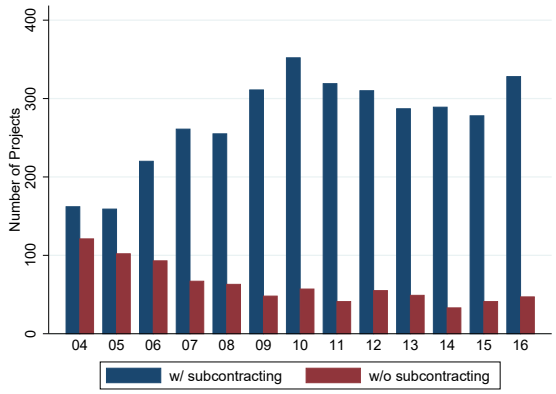
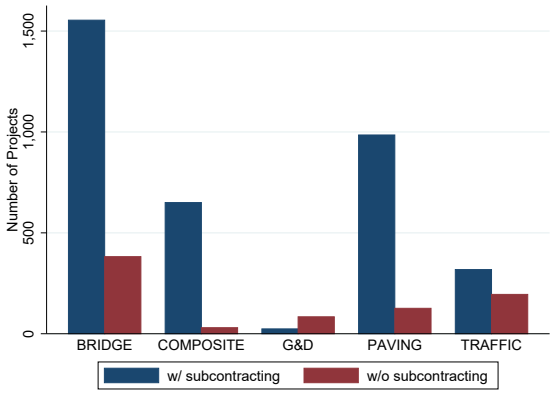
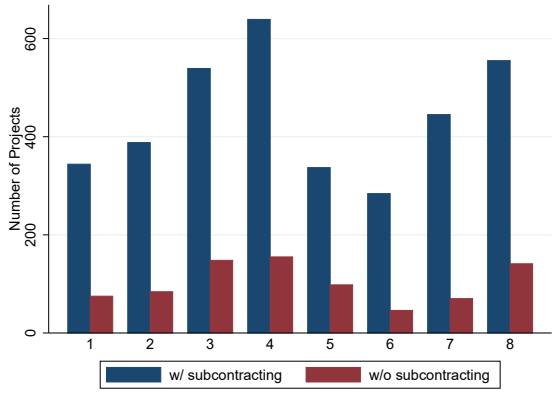
Figure 1: Project Numbers by Year, Type, Location and DBE Status



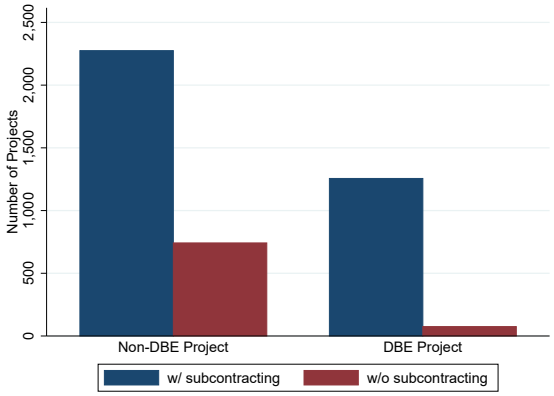
(a) Project Numbers over Time



(b) Project Numbers by Type



(c) Project Numbers by Location



(d) Project Numbers by DBE Status

Figure 2: Division Map

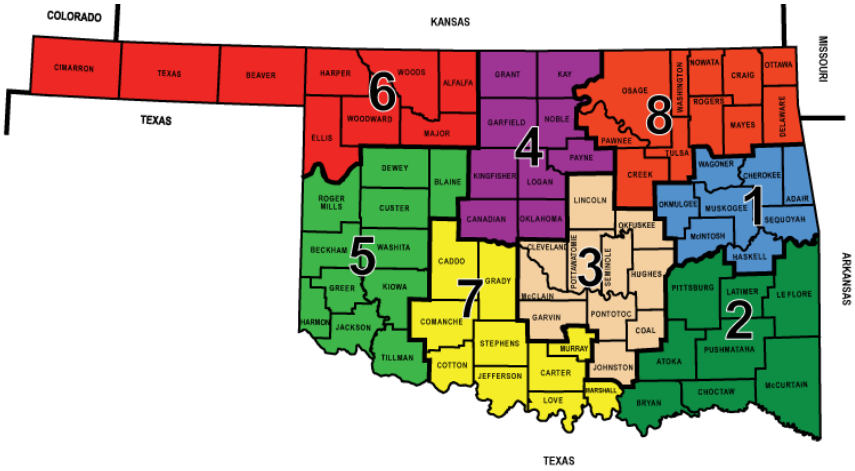


Figure 3: DBE requirement and DBE Firm Participation

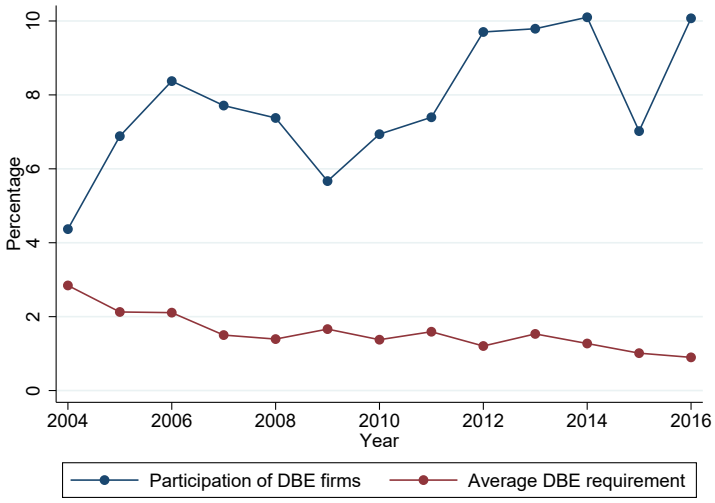
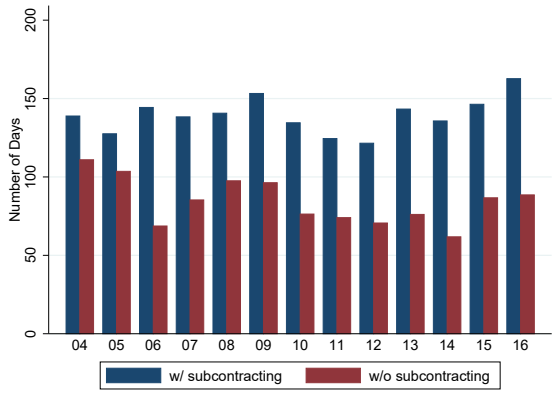
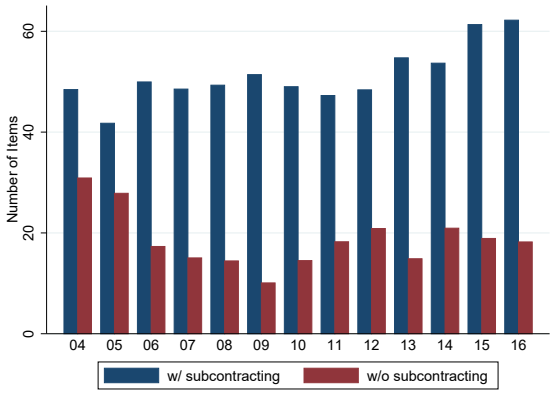


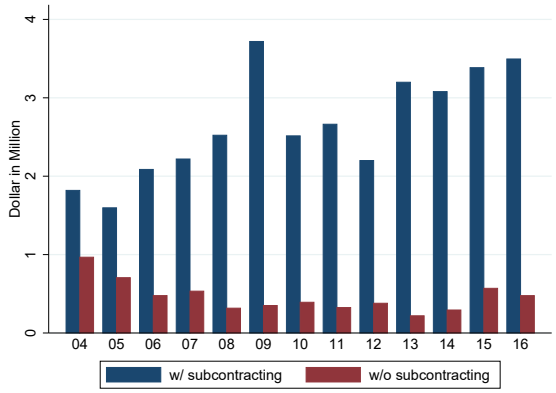
Figure 4: Duration, Complexity and Monetary Value of Projects



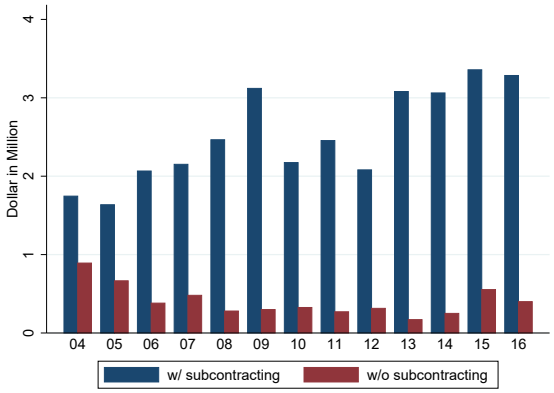
(a) Project Average Duration



(b) Project Average Complexity



(c) Project Average Engineer's Estimate



(d) Project Average Winning Bid

Figure 5: Average Subcontracting Amount in a Project with Subcontracting

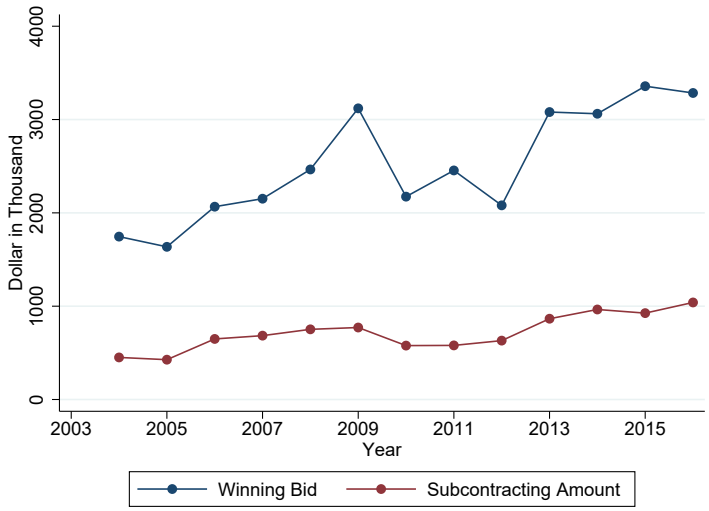
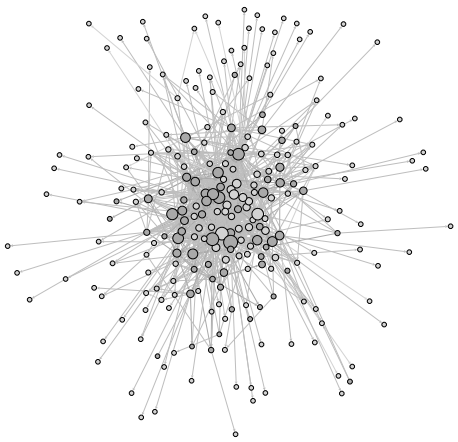
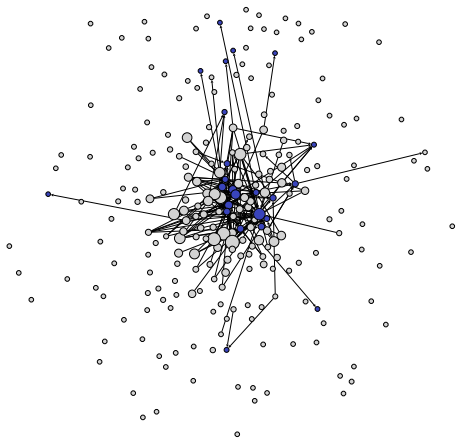


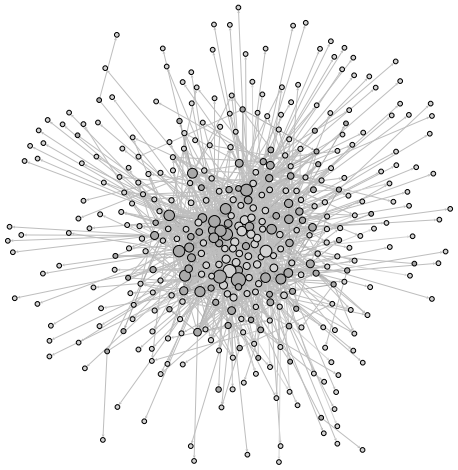
Figure 6: Subcontracting Network and DBE firms over Time



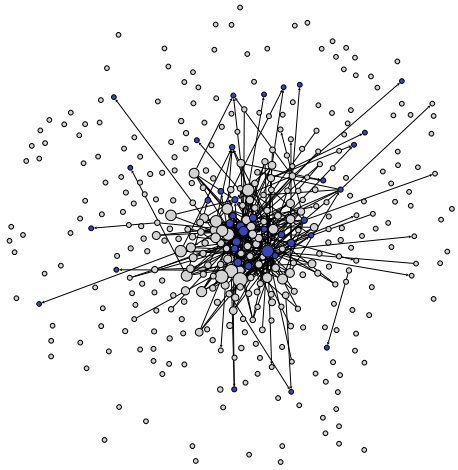
(a) Network in 2006M1



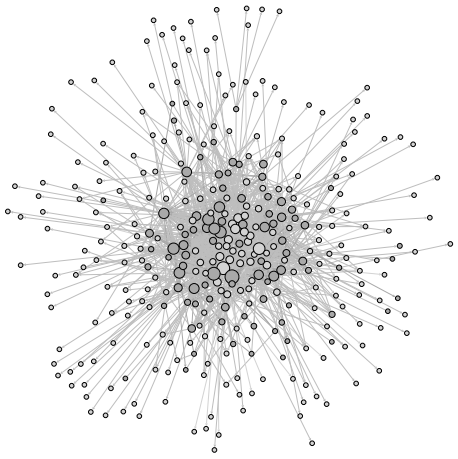
(b) DBE Network in 2006M1



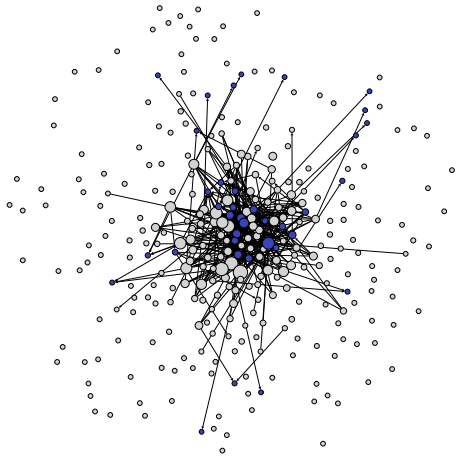
(c) Network in 2011M1



(d) DBE Network in 2011M1



(e) Network in 2016M1



(f) DBE Network in 2016M1

Table 1: Summary Statistics

	OB	Mean	SD	Min	Max
$PlanNumber_{pmt}$	3429	6.517	3.061	1.000	20.000
$BidderNumber_{pmt}$	3429	3.812	1.907	1.000	11.000
$SubNumber_{pmt}$	3429	3.661	3.149	0.000	22.000
$PotentialSubNumber_{pmt}$	3429	456.797	55.784	346.000	535.000
$Cdays_{pmt}$	3429	128.504	104.122	5.000	1129.000
$EngEst_{pmt}$ (in thousand dollars)	3429	2397.350	5776.487	12.632	96537.186
$ItemNumber_{pmt}$	3429	45.713	50.171	1.000	616.000
$ProjectDBE_{pmt}$	3429	0.298	0.458	0.000	1.000
$Distance_{ipmt}$	13072	184.125	265.017	1.023	1635.666
$RivalLinkMax_{ipmt}$	13072	78.337	61.075	0.000	257.000
$Distance_{jpmt}$	1566357	247.752	277.109	0.218	1696.163
$RivalLinkMax_{jpmt}$	1566357	221.881	54.220	76.000	316.000
$SubEntrant_{jpmt}$	1566357	0.170	0.376	0.000	1.000
$FirmDBE_{i(j)}$	962	0.072	0.258	0.000	1.000
$PrimeEx_i$	962	0.075	0.263	0.000	1.000
$SubEx_j$	962	0.693	0.461	0.000	1.000
$Prime\&Sub_{i(j)}$	962	0.154	0.361	0.000	1.000
$Perspective_{i(j)}$	962	0.078	0.268	0.000	1.000
$Backlog_{i(j)t}$ (in thousand dollars)	126984	371.830	2959.113	0.000	117189.568
$BacklogPrimeWork_{i(j)t}$ (in thousand dollars)	126984	262.089	2744.191	0.000	113371.952
$BacklogSubWork_{i(j)t}$ (in thousand dollars)	126984	109.741	644.468	0.000	24093.696
$DegreeCentrality_{it}$	126984	2.514	13.405	0.000	257.000
$HubCentrality_{it}$	126984	0.001	0.006	0.000	0.177
$SubAmount_{it}$ (in thousand dollars)	126984	419.055	3072.660	0.000	88041.931
$DegreeCentrality_{jt}$	126984	2.514	12.766	0.000	342.000
$AuthCentrality_{jt}$	126984	0.001	0.005	0.000	0.126
$SubAmount_{jt}$ (in thousand dollars)	126984	419.055	1778.398	0.000	39594.695
$Network_{ijt}$	122031624	0.001	0.035	0.000	1.000
$NetworkSum_{ijt}$	122031624	0.003	0.109	0.000	29.000
$MetricDistance_{ijt}$	122031624	0.523	0.485	0.000	1.414
$Distance_{ij}$	924482	385.988	372.619	0.000	2720.764
$ProjectValue_{mt}$ (in million dollars)	1056	8.891	13.892	0.000	136.748

Notes: The table presents the summary statistics of variables at various levels.

Table 2: Prime Contractor States

State	FirmNumber	FirmNumberPct	SubProjectNumber	SubProjectNumberPct	SubAmount	SubAmountPct
Arizona	1	0.005	76	0.005	6.4263	0.0025
Arkansas	4	0.018	40	0.003	4.6173	0.0018
Colorado	3	0.014	52	0.003	11.7883	0.0045
Florida	13	0.059	65	0.004	12.2188	0.0047
Illinois	1	0.005	252	0.016	34.2130	0.0131
Indiana	3	0.014	55	0.004	3.2105	0.0012
Iowa	3	0.014	90	0.006	14.0010	0.0054
Kansas	19	0.086	1404	0.091	241.9375	0.0929
Kentucky	2	0.009	11	0.001	0.7133	0.0003
Michigan	5	0.023	24	0.002	4.4294	0.0017
Minnesota	5	0.023	60	0.004	9.6898	0.0037
Missouri	9	0.041	85	0.005	9.1907	0.0035
Nebraska	3	0.014	180	0.012	48.9024	0.0188
New Jersey	1	0.005	2	0.000	0.1256	0.0000
Ohio	6	0.027	8	0.001	0.7586	0.0003
Oklahoma	129	0.586	12770	0.824	2175.8936	0.8355
Pennsylvania	2	0.009	0	0.000	0.0000	0.0000
Tennessee	1	0.005	4	0.000	0.5244	0.0002
Texas	9	0.041	268	0.017	22.7305	0.0087
Washington	1	0.005	44	0.003	2.7965	0.0011
Total	220	1	15490	1	2604.168	1

Notes: The table presents the states of prime contractors and their subcontracting behaviors in each state. *SubAmount* is in millions of dollars.

Table 3: Subcontractor States

State	FirmNumber	FirmNumberPct	SubProjectNumber	SubProjectNumberPct	SubAmount	SubAmountPct
Alabama	2	0.002	2	0.0001	0.2797	0.00011
Arizona	1	0.001	1	0.0001	0.5549	0.00021
Arkansas	22	0.027	124	0.0080	16.0099	0.00615
California	4	0.005	6	0.0004	0.6205	0.00024
Colorado	4	0.005	17	0.0011	5.0964	0.00196
Delaware	1	0.001	1	0.0001	0.2268	0.00009
Florida	13	0.016	27	0.0017	10.3245	0.00396
Georgia	6	0.007	23	0.0015	3.4642	0.00133
Illinois	8	0.010	202	0.0130	60.6310	0.02328
Indiana	6	0.007	11	0.0007	0.7747	0.00030
Iowa	6	0.007	16	0.0010	15.5961	0.00599
Kansas	58	0.071	408	0.0263	161.1014	0.06186
Kentucky	1	0.001	1	0.0001	0.1436	0.00006
Maryland	2	0.002	4	0.0003	3.9815	0.00153
Michigan	5	0.006	9	0.0006	1.9857	0.00076
Minnesota	9	0.011	96	0.0062	8.5136	0.00327
Missouri	32	0.039	180	0.0116	62.0677	0.02383
Nebraska	5	0.006	11	0.0007	5.4808	0.00210
Nevada	2	0.002	3	0.0002	0.7284	0.00028
New Jersey	1	0.001	13	0.0008	9.6328	0.00370
New York	1	0.001	1	0.0001	0.0760	0.00003
North Carolina	1	0.001	1	0.0001	0.0850	0.00003
North Dakota	1	0.001	1	0.0001	0.0016	0.00000
Ohio	2	0.002	2	0.0001	0.1630	0.00006
Oklahoma	528	0.648	13601	0.8781	2134.5892	0.81968
Pennsylvania	4	0.005	80	0.0052	2.1204	0.00081
Tennessee	4	0.005	7	0.0005	0.1725	0.00007
Texas	70	0.086	555	0.0358	82.7036	0.03176
Utah	3	0.004	4	0.0003	6.1075	0.00235
Virginia	2	0.002	14	0.0009	0.4661	0.00018
Washington	3	0.004	3	0.0002	0.5585	0.00021
Wisconsin	6	0.007	63	0.0041	8.8011	0.00338
Wyoming	2	0.002	3	0.0002	1.1089	0.00043
Total	815	1.000	15490	1.0000	2604.1677	1.00000

Notes: The table presents the states of subcontractors and their subcontracting behaviors in each state. *SubAmount* is in millions of dollars.

Table 4: Estimation Results

	Regular Network				Discounted Network			
	All		Subcontracting Projects		All		Subcontracting Projects	
	Bidder	Sub	Bidder	Sub	Bidder	Sub	Bidder	Sub
$Network_{ij,t-1}$	-0.7588^{***}	3.0156^{***}	-0.6411^{***}	2.9176^{***}	-0.6271^{***}	2.8040^{***}	-0.6888^{***}	3.1267^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$NetworkSum_{ij,t-1}$	0.9844^{***}	5.1545^{***}	1.0061^{***}	5.7677^{***}	1.8430^{***}	9.2666^{***}	1.9344^{***}	9.6674^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$NetworkSum_{ij,t-1}BidderDBE_i$	0.3930^{*}	1.0224	0.3766^{*}	1.0378	0.6057	0.8854	0.6988^{*}	0.9088
	(0.080)	(0.142)	(0.084)	(0.144)	(0.108)	(0.190)	(0.060)	(0.194)
$NetworkSum_{ij,t-1}SubDBE_j$	-0.1551^{***}	-0.4574	-0.1179^{*}	-0.2995	-0.2610^{**}	0.0086	-0.2481^{***}	0.2485
	(0.000)	(0.168)	(0.072)	(0.370)	(0.018)	(0.482)	(0.000)	(0.360)
$log(Distance)_{ij}$	-0.4376^{***}	-4.7547^{***}	-0.9650^{***}	-3.3459^{***}	-0.6845^{***}	-4.6204^{***}	-0.8491^{***}	-3.7828^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$log(Distance)^2_{ij}$	1.2309^{***}	-0.1136	1.1394^{***}	-0.5159^{***}	2.4877^{***}	-0.0974	1.5226^{***}	-0.4907^{*}
	(0.000)	(0.428)	(0.000)	(0.002)	(0.000)	(0.428)	(0.000)	(0.064)
$log(Distance)_{ipmt}$	0.2769^{***}	-2.0613^{***}	0.2483^{***}	0.0172	0.0680^{*}	-0.8560^{***}	0.4117^{***}	-1.1795^{***}
	(0.000)	(0.000)	(0.000)	(0.312)	(0.078)	(0.000)	(0.000)	(0.000)
$log(Distance)^2_{ipmt}$	-0.4628^{***}	0.6383	-0.6143^{***}	-0.6738^{**}	-0.1528	0.3215	-0.8286^{***}	0.2155
	(0.000)	(0.148)	(0.000)	(0.042)	(0.174)	(0.188)	(0.000)	(0.188)
$log(Distance)_{jpmt}$	-0.9271^{***}	-3.1591^{***}	-1.0305^{***}	-2.6268^{***}	-1.0967^{***}	-2.4522^{***}	-0.9870^{***}	-2.2413^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$log(Distance)^2_{jpmt}$	-2.3068^{***}	-2.4960^{***}	-1.9731^{***}	-2.5309^{***}	-2.0848^{***}	-2.7300^{***}	-2.9754^{***}	-2.7494^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$log(Distance)_{ij}log(Distance)_{ipmt}$	1.7806^{***}	2.8293^{***}	2.0924^{***}	1.6038^{***}	1.2321^{***}	1.5799^{***}	1.7220^{***}	1.6742^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$log(Distance)_{ij}log(Distance)_{jpmt}$	-0.2773^{***}	0.9230^{***}	-0.2406^{*}	-0.1926	-0.8615^{***}	0.3665	-0.5387^{***}	0.3047
	(0.000)	(0.000)	(0.076)	(0.148)	(0.000)	(0.296)	(0.000)	(0.196)
$log(Distance)_{ipmt}log(Distance)_{jpmt}$	-1.2755^{***}	0.0044	-2.3128^{***}	-0.5307^{***}	-1.4183^{***}	-0.8689^{***}	-1.3632^{***}	-0.4836^{***}
	(0.000)	(0.346)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$log(Distance)_{ipmt}log(Distance)_{jpmt}log(Distance)_{ij}$	-2.6761^{***}	0.7368^{**}	-0.7521^{***}	0.6200	-1.7545^{***}	1.4229^{***}	-0.9019^{***}	0.9562^{**}
	(0.000)	(0.018)	(0.000)	(0.182)	(0.000)	(0.000)	(0.000)	(0.014)
$MetricDistance_{ij,t-1}$	0.0306^{**}	-0.5976^{***}	-0.0187	-0.6008^{***}	0.0327^{***}	-0.6139^{***}	-0.1640^{***}	-0.4086^{***}
	(0.024)	(0.000)	(0.102)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

The probability that the parameter has the opposite sign of its mean is shown in parentheses. $*p < 0.1, **p < 0.05, ***p < 0.01$.

Table 4: Estimation Results (Continued)

	Regular Network				Discounted Network			
	All		Subcontracting Projects		All		Subcontracting Projects	
	Bidder	Sub	Bidder	Sub	Bidder	Sub	Bidder	Sub
$RivalLinkMax_{i,t-1}$	-0.3108^{***}		-0.3659^{***}		-0.5413^{***}		-0.5930^{***}	
	(0.000)		(0.000)		(0.000)		(0.000)	
$log(Backlog)_{i,t-1}$	-0.6117^{***}	0.2465^{***}	-0.5738^{***}	0.1204^{***}	-0.5470^{***}	0.2015^{***}	-0.4932^{***}	0.0747^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$log(Backlog)^2_{i,t-1}$	0.1539^{***}	0.0504^{***}	0.1822^{***}	0.0536^{***}	0.1095^{***}	0.0994^{***}	0.1432^{***}	0.0908^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$DegreeCentrality_{i,t-1}$	-0.6537^{***}	-0.4616^{***}	-0.8029^{***}	-0.2209^{***}	-1.6270^{***}	-0.4681^{***}	-1.6590^{***}	-0.4097^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$DegreeCentrality_{i,t-1}BidderDBE_i$	-0.2285	-0.8278	-0.3974	-0.7802	-0.0206	-0.4117	-0.1489	-0.1599
	(0.308)	(0.160)	(0.250)	(0.178)	(0.498)	(0.284)	(0.414)	(0.414)
$log(SubAmount)_{i,t-1}$	-0.1598^{***}	-0.3113^{***}	-0.1324^{***}	-0.3455^{***}	-0.1077^{***}	-0.3547^{***}	-0.2253^{***}	-0.2651^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$HubCentrality_{i,t-1}$	-0.9923	0.7899	-0.4219	0.3985	-0.2096	0.8701	0.1507	0.5731
	(0.120)	(0.136)	(0.262)	(0.320)	(0.356)	(0.106)	(0.478)	(0.224)
$HubCentrality_{i,t-1}BidderDBE_i$	-0.1306	-0.2737	-0.1188	-0.3484	-0.1232	-0.3315	-0.0755	-0.2879
	(0.452)	(0.394)	(0.460)	(0.352)	(0.464)	(0.362)	(0.468)	(0.374)
$ProjectDBE_{pmt}BidderDBE_i$	-0.3151^{**}	0.3687	-0.2480^{*}	0.2879	-0.2588^{**}	0.2709^{*}	-0.2583^{*}	0.3463
	(0.028)	(0.142)	(0.064)	(0.138)	(0.040)	(0.086)	(0.072)	(0.128)

The probability that the parameter has the opposite sign of its mean is shown in parentheses. $*p < 0.1, **p < 0.05, ***p < 0.01$.

Table 4: Estimation Results (Continued)

	Regular Network				Discounted Network			
	All		Subcontracting Projects		All		Subcontracting Projects	
	Bidder	Sub	Bidder	Sub	Bidder	Sub	Bidder	Sub
$RivalLinkMax_{j,t-1}$		-0.0610^{***}		-0.0305^{***}		-0.2430^{***}		-0.1691^{***}
		(0.000)		(0.000)		(0.000)		(0.000)
$SubEntrant_{jt}$	-1.6865^{***}	2.3366^{***}	-1.8525^{***}	2.7754^{***}	-1.6799^{***}	2.3662^{***}	-2.1152^{***}	3.1400^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$log(Backlog)_{j,t-1}$	-0.3952^{***}	-0.1443^{***}	-0.4072^{***}	0.4763^{***}	-0.4129^{***}	-0.0031	-0.2865^{***}	0.3513^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.480)	(0.000)	(0.000)
$log(Backlog)^2_{j,t-1}$	-0.1965^{***}	0.9574^{***}	0.1322^{***}	0.1900^{***}	-0.2929^{***}	0.8987^{***}	0.0654^{***}	0.1914^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$DegreeCentrality_{j,t-1}$	-0.1059^{***}	0.9353^{***}	0.0385^{***}	0.8014^{***}	0.0623^{***}	1.2966^{***}	-0.2252^{***}	2.0443^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$DegreeCentrality_{j,t-1}SubDBE_j$	0.3375^{***}	-0.8522^{***}	0.0687^{***}	-0.4610^{***}	0.2660^{***}	-0.7831^{***}	0.3411^{***}	-1.3056^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$log(SubAmount)_{j,t-1}$	-0.0323^{***}	-0.1689^{***}	-0.0428^{***}	-0.1037^{***}	-0.0347^{***}	-0.1040^{***}	0.0088	-0.1413^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.300)	(0.000)
$AuthCentrality_{j,t-1}$	-0.2054	0.2393	-0.5842	0.0596	0.6656	0.7583	0.8221	0.5040
	(0.378)	(0.412)	(0.220)	(0.488)	(0.228)	(0.278)	(0.150)	(0.274)
$AuthCentrality_{j,t-1}SubDBE_j$	0.2944	0.2270	0.8674	0.1583	0.6328	0.0639	0.9683	0.0786
	(0.294)	(0.424)	(0.148)	(0.486)	(0.166)	(0.498)	(0.120)	(0.460)
$ProjectDBE_{pmt}SubDBE_j$	0.2430^{***}	0.2641^{***}	0.2146^{***}	0.2870^{***}	0.1984^{***}	0.3459^{***}	0.2172^{***}	0.3056^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

The probability that the parameter has the opposite sign of its mean is shown in parentheses. $*p < 0.1, **p < 0.05, ***p < 0.01$.

Table 4: Estimation Results (Continued)

	Regular Network				Discounted Network			
	All		Subcontracting Projects		All		Subcontracting Projects	
	Bidder	Sub	Bidder	Sub	Bidder	Sub	Bidder	Sub
$log(Cdays)_{pmt}$	1.1046^{***}	0.6312^{***}	0.8136^{***}	0.3894^{***}	1.3707^{***}	0.7269^{***}	0.9228^{***}	0.1998^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$log(EngEst)_{pmt}$	0.0601^{***}	-0.0286^{***}	0.0551^{***}	-0.1328^{***}	-0.0405^{***}	0.1216^{***}	0.1023^{***}	0.0942^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$log(ItemNumber)_{pmt}$	3.9565^{***}	4.4091^{***}	3.7863^{***}	4.1404^{***}	3.7850^{***}	4.1591^{***}	3.9945^{***}	3.3741^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$ProjectDBE_{pmt}$	-0.1034^{***}	0.0631^{***}	-0.0870^{***}	0.0364	-0.0764^{***}	-0.0001	-0.0654^{***}	-0.0132
	(0.000)	(0.000)	(0.000)	(0.172)	(0.000)	(0.420)	(0.000)	(0.380)
$PlanNumber_{pmt}$	-0.7865^{***}	0.0485^{**}	-0.7828^{***}	0.0821^{***}	-0.7286^{***}	-0.0691^{***}	-0.7242^{***}	-0.0417^{*}
	(0.000)	(0.036)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.092)
$log(ProjectValue)_{m,t+1}$	0.0375^{***}	-0.1372^{***}	0.0103	-0.1791^{***}	0.0512^{***}	-0.1932^{***}	0.0214^{***}	-0.1126^{***}
	(0.000)	(0.000)	(0.342)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Division Fixed Effect	Yes		Yes		Yes		Yes	
Project Type Fixed Effect	Yes		Yes		Yes		Yes	
Bidder Fixed Effect	Yes		Yes		Yes		Yes	
Subcontractor Fixed Effect	Yes		Yes		Yes		Yes	
Time Fixed Effect	Yes		Yes		Yes		Yes	

The probability that the parameter has the opposite sign of its mean is shown in parentheses. $*p < 0.1, **p < 0.05, ***p < 0.01$.

Table 5: Summary Statistics for the Bidding Regression Data Set

	OB	Mean	SD	Min	Max
$WinBid$ (in thousand dollars)	3005	2093.6	4959.8	9.399	90449.9
$Subcontracting$	3005	0.849	0.358	0	1
$SubPercentage$	3005	0.193	0.175	0	0.942
$SubItemNumber$	3005	22.15	33.96	0	337
$SubNumber$	3005	3.506	3.028	0	22
$ProjectDBE$	3005	0.285	0.451	0	1
$PrimeDBE$	3005	0.0606	0.239	0	1
$SubDBE$	3005	0.595	0.491	0	1
$ProjectDBEpercent$	3005	1.356	2.374	0	10
$EngineerEstimate$ (in thousand dollars)	3005	2232.8	5445.2	12.63	90784
$BidderNumber$	3005	3.766	1.896	1	13
$CalanderDays$	3005	123.6	101.4	5	1129
$ItemNumber$	3005	45.07	48.59	1	489
$PrimeBacklog$ (in thousand dollars)	3005	5810.5	10419.4	0	91360.6
$Distance$	3005	119.3	187.2	1.025	1155.5
$DegreeCentrality_{t-1}$	3005	54.49	50.33	0	257
$PrimeInState$	3005	0.881	0.324	0	1
$ProjectValue_{t+1}$ (in million dollars)	3005	9.021	14.32	0	136.7
$RivalMinBacklog$ (in thousand dollars)	3005	10468.9	29037.1	0	105570.6

Table 6: Impact of Subcontracting on Bidding Outcomes

	(1)	(2)	(3)	(4)	(5)	(6)
	$log(WinBid)$	$log(WinBid)$	$log(WinBid)$	$log(WinBid)$	$log(WinBid)$	$log(WinBid)$
$Subcontracting$	0.0872***	0.553***				
	(0.0138)	(0.138)				
$Subcontracting \times log(EngEst)$		-0.0373***	0.0443***			
		(0.0107)	(0.00828)			
$Subcontracting \times (log(EngEst))^2$			-0.00299***			
			(0.000633)			
$SubPercentage$				0.268***		
				(0.0573)		
$SubPercentage^2$				-0.272***		
				(0.0856)		
$SubItemNumber$					0.000548*	
					(0.000290)	
$SubItemNumber^2$					-0.00000243**	
					(0.000000975)	
$SubNumber$						0.0180***
						(0.00382)
$SubNumber^2$						-0.00121***
						(0.000248)
$SubDBE$	0.00659	0.00843	0.00658	0.0183**	0.0284***	0.0139
	(0.00854)	(0.00850)	(0.00852)	(0.00811)	(0.00790)	(0.00848)
$PrimeDBE$	-0.0671***	-0.0525***	-0.0549***	-0.0763***	-0.0908***	-0.0811***
	(0.0194)	(0.0199)	(0.0196)	(0.0197)	(0.0198)	(0.0200)
$ProjectDBE \times PrimeDBE$	0.101*	0.0700	0.0672	0.115**	0.110*	0.107*
	(0.0598)	(0.0595)	(0.0589)	(0.0574)	(0.0589)	(0.0579)
$ProjectDBE \times PrimeDBE \times t$	-0.000136	-0.0000279	-0.0000277	-0.000115	0.0000232	-0.0000110
	(0.000464)	(0.000458)	(0.000453)	(0.000455)	(0.000459)	(0.000456)
$ProjectDBE \times SubDBE$	-0.0471***	-0.0438***	-0.0434***	-0.0510***	-0.0518***	-0.0527***
	(0.0142)	(0.0142)	(0.0141)	(0.0143)	(0.0143)	(0.0144)
$ProjectDBE \times SubDBE \times t$	0.000369***	0.000383***	0.000406***	0.000358***	0.000342***	0.000365***
	(0.000130)	(0.000130)	(0.000129)	(0.000131)	(0.000132)	(0.000132)

Standard error in parentheses is robust. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Impact of Subcontracting on Bidding Outcomes (continued)

	(1)	(2)	(3)	(4)	(5)	(6)
	$log(WinBid)$	$log(WinBid)$	$log(WinBid)$	$log(WinBid)$	$log(WinBid)$	$log(WinBid)$
$log(EngEst)$	0.958***	0.989***	0.990***	0.959***	0.957***	0.957***
	(0.00511)	(0.0107)	(0.00975)	(0.00513)	(0.00535)	(0.00525)
$log(BidderNumber)$	-0.113***	-0.114***	-0.115***	-0.110***	-0.109***	-0.111***
	(0.00734)	(0.00735)	(0.00735)	(0.00737)	(0.00744)	(0.00739)
$log(Cdays)$	0.0521***	0.0508***	0.0497***	0.0509***	0.0515***	0.0493***
	(0.00931)	(0.00929)	(0.00926)	(0.00930)	(0.00932)	(0.00939)
$log(ItemNumber)$	0.0426***	0.0442***	0.0455***	0.0413***	0.0467***	0.0439***
	(0.00727)	(0.00730)	(0.00734)	(0.00750)	(0.00879)	(0.00780)
$log(PrimeBacklog)$	-0.000208	0.0000359	0.000159	-0.000239	-0.000110	-0.000100
	(0.000956)	(0.000955)	(0.000955)	(0.000967)	(0.000969)	(0.000961)
$log(Distance)$	0.00523	0.00464	0.00494	0.00354	0.00379	0.00520
	(0.00399)	(0.00399)	(0.00398)	(0.00400)	(0.00399)	(0.00400)
$DegreeCentrality_{t-1}$	0.000218***	0.000218***	0.000193**	0.000255***	0.000272***	0.000193**
	(0.0000822)	(0.0000819)	(0.0000820)	(0.0000826)	(0.0000832)	(0.0000843)
$PrimeInState$	-0.0109	-0.0105	-0.00912	-0.00951	-0.00653	-0.00582
	(0.0142)	(0.0142)	(0.0142)	(0.0143)	(0.0144)	(0.0143)
$log(ProjectValue)_{t+1}$	-0.000452	-0.000518	-0.000489	-0.000492	-0.000472	-0.000507
	(0.000500)	(0.000499)	(0.000500)	(0.000504)	(0.000507)	(0.000506)
$log(RMinbacklog)$	-0.00124**	-0.00125**	-0.00122**	-0.00112**	-0.00110**	-0.00123**
	(0.000542)	(0.000541)	(0.000540)	(0.000546)	(0.000550)	(0.000547)
$UnemploymentRate$	-0.0382***	-0.0380***	-0.0379***	-0.0380***	-0.0383***	-0.0381***
	(0.00410)	(0.00410)	(0.00409)	(0.00412)	(0.00415)	(0.00413)
$log(BuildingPermit)$	-0.00354	-0.00312	-0.00284	-0.00704	-0.00868	-0.00403
	(0.0143)	(0.0142)	(0.0142)	(0.0144)	(0.0143)	(0.0144)
Constant	0.393**	0.00145	-0.0109	0.451**	0.494***	0.437**
	(0.188)	(0.226)	(0.219)	(0.190)	(0.191)	(0.191)
Observations	3005	3005	3005	3005	3005	3005
$PrimeDBE + ProjectDBE \times PrimeDBE$	0.0336	0.0175	0.0123	0.0382	0.0192	0.0264
F-text P-value	0.564	0.761	0.830	0.492	0.736	0.639
$SubDBE + ProjectDBE \times SubDBE$	-0.0405	-0.0353	-0.0368	-0.0328	-0.0234	-0.0388
F-text P-value	0.00669	0.0172	0.0128	0.0261	0.113	0.0109

Standard error in parentheses is robust. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Summary Statistics for the Market Participation Regression Data Set

	OB	Mean	SD	Min	Max
$Exit$	77170	0.463	0.499	0	1
$UnemploymentRate$	77170	4.917	0.902	3.200	7
$BuildingPermit$	77170	157893.9	42323.8	70255.3	232023.3
$DegreeCentrality_i$	77170	4.129	17.00	0	257
$DegreeCentrality_j$	77170	4.121	16.17	0	342
$InState$	77170	0.660	0.474	0	1
$Prime$	77170	0.0685	0.253	0	1
Sub	77170	0.389	0.487	0	1
$FirmDBE$	77170	0.0805	0.272	0	1
$Prime \times Sub$	77170	0.111	0.315	0	1
$DBEPercentAsPrime$	77170	1.758	8.245	0	154
$DBEPercentAsSub$	77170	10.71	37.56	0	678
$DBEProjectAsPrime$	77170	0.0881	0.283	0	1
$DBEProjectAsSub$	77170	0.364	0.481	0	1

Table 8: Impact on Frims' Market Participation

	(1)	(2)	(3)	(4)
	Exit	*Exit*	*Exit*	*Exit*
Prime	-2.765***	-2.731***	-2.351***	-2.325***
	(0.0433)	(0.0441)	(0.0463)	(0.0471)
Sub	-2.150***	-1.871***	-1.755***	-1.470***
	(0.0285)	(0.0303)	(0.0305)	(0.0328)
$Prime \times Sub$	-3.455***	-3.163***	-3.127***	-2.818***
	(0.0791)	(0.0799)	(0.0822)	(0.0830)
FirmDBE	-1.186***	-1.184***	-1.230***	-1.230***
	(0.0440)	(0.0441)	(0.0498)	(0.0498)
DBEPercentAsPrime	0.0112		0.00322	
	(0.00688)		(0.00740)	
DBEPercentAsSub	-0.0927***		-0.101***	
	(0.00356)		(0.00368)	
DBEProjectAsPrime		-0.308***		-0.226**
		(0.0885)		(0.0932)
DBEProjectAsSub		-0.835***		-0.847***
		(0.0312)		(0.0336)
UnemploymentRate	0.114***	0.128***	0.148***	0.165***
	(0.0154)	(0.0153)	(0.0148)	(0.0148)
$log(BuildingPermit)$	0.793***	0.832***	0.823***	0.833***
	(0.0461)	(0.0461)	(0.0471)	(0.0471)
$DegreeCentrality_i$	-0.0509***	-0.0390***	-0.0474***	-0.0406***
	(0.00424)	(0.00359)	(0.00455)	(0.00383)
$DegreeCentrality_j$	-0.149***	-0.264***	-0.104***	-0.248***
	(0.0109)	(0.00972)	(0.0111)	(0.00986)
InState	-0.163***	-0.162***	-0.133***	-0.127***
	(0.0216)	(0.0216)	(0.0236)	(0.0236)
Constant	-8.106***	-8.636***	-8.913***	-9.129***
	(0.604)	(0.603)	(0.609)	(0.609)
Observations	77170	77170	57963	57963
Last 24 Months Dropped	No	No	Yes	Yes

Standard errors in parentheses

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

Appendix

A Estimating Parameters

In this section, we outline how to estimate β as discussed in Section 3. The methodology is following He and Kosmopoulou (2021) adapted to our framework of analysis. We use the Markov-Chain-Monte-Carlo (MCMC) method to update the estimates of the parameters and get a converged posterior distribution after 2000 of iterations. We assume β contains N parameters and follows a prior normal distribution $N(0, I_N)$, where I_N is the identity matrix, and $\beta_0 = 0$. Letting q denote the iteration number and n index the element in β, we update β from β_q^n to β_{q+1}^n as follows. We first randomly draw a β^n from $N(\beta_q^n, 1)$. We then calculate the likelihood ratio

$$r = min\{1, \frac{\mathcal{L}(\beta^n | Link, \beta_{q+1}^1, ..., \beta_{q+1}^{n-1}, \beta_q^{n+1}, ..., \beta_q^N) p(\beta^n)}{\mathcal{L}(\beta_q^n | Link, \beta_{q+1}^1, ..., \beta_{q+1}^{n-1}, \beta_q^{n+1}, ..., \beta_q^N) p(\beta_q^n)}\}, \tag{8}$$

where p is the density function of the standard normal distribution. Depending on the likelihood ratio r, β_{q+1}^n will be determined by the following equation,

$$\beta_{q+1}^n = \begin{cases} \beta^n & \text{with probability } r \\ \beta_q^n & \text{with probability } 1 - r. \end{cases} \tag{9}$$

Table A1: Variables

Variable	Explanation
	Firms' network characteristics
$Network_{ij,t-1}$	A dummy variable indicating whether prime contractor i and subcontractor j have formed a subcontracting link in the previous 24 months.
$NetworkSum_{ij,t-1}$	The sum of all links formed between prime contractor i and subcontractor j in the previous 24 months.
$DegreeCentrality_{i,t-1}$/ $DegreeCentrality_{j,t-1}$	The number of links of prime contractor i/ subcontractor j in period 24 months. A centrality measurement capturing the relative importance of the carrier in the network.
$HubCentrality_{i,t-1}$	A centrality measurement in $[0, 1]$, capturing the relative importance of prime contractor i in the network compared to other prime contractors. The measure captures not only how many subcontractors contractor i connects to, but also considers the importance of the firms i is connecting to, based on links established in the past 24 months.
$AuthCentrality_{j,t-1}$	A centrality measurement in $[0, 1]$, capturing the relative importance of subcontractor j compared to other subcontractors. The measure captures not only how many primes subcontractor j connects to, but also considers the importance of the primes j is connecting to, based on links established in the past 24 months.
	Rivals' network characteristics
$RivalLinkMax_{i,t-1}$/ $RivalLinkMax_{j,t-1}$	The max number of subcontracting relationships (links) the rivals of prime contractor i/ subcontractor j had formed (links) in the previous 24 months.
	Homophily
$MetricDistance_{ij,t-1}$	The metric distance between the potential prime contractor i's and potential subcontractor j's workload distributions across different work types in the previous 24 months.
$log(Distance)_{ij}$	The distance between the zip codes of firm i's and j's locations. The zip code location is measured by the longitude and latitude at the centroid of the zip code area.
	Business environment
$ProjectValue_{m,t+1}$	The real value of projects in division m in the next month.

Table A1: Variables (Continued)

Variable	Explanation
	Firms' other characteristics
$log(Distance)_{ipmt}$/ $log(Distance)_{jpmt}$	The logarithm of the distance between the county the project is located in and the zip code of prime i's/subcontractor j's location. The county location is measured by the longitude and latitude at the centroid of the county. The zip code location is measured by the longitude and latitude at the centroid of the zip code area.
$log(SubAmount)_{i,t-1}$	The dollar amount of the work that a prime contractor i offered to subcontractors in the last 24 months.
$log(SubAmount)_{j,t-1}$	The dollar amount of the work that a subcontractor j accepted from prime contractors in the last 24 months.
$log(Backlog)_{i,t-1}$/ $log(Backlog)_{j,t-1}$	For each project awarded, both the value of the contract and the length of the contract in days are given. We assume that a project is completed in a uniform fashion over the length of the contract. A contract backlog for prime contractor i/subcontractor j is constructed in each month by summing across the remaining value of all existing contracts in Oklahoma for that firm. As projects are completed, the backlog of a firm goes to zero unless new contracts are won. The backlog for a firm i is calculated with the amount that is not subcontracted out when the firm is a prime contractor and with the amount that is subcontracted to the firm when it is the subcontractor. We use the $log(Backlog + 1)$ in the estimation.
$SubEntrant_{jt}$	A dummy indicating the potential subcontractor j is a potential entrant in time t.
	Auction characteristics
$log(Cdays)_{pmt}$	The logarithm of the number of days to complete the project assigned by ODOT in project p.
$log(EngEst)_{pmt}$	The logarithm of the Engineer's Estimate of the project p value.
$log(ItemNumber)_{pmt}$	The logarithm of the number of items in project p.
$ProjectDBE_{pmt}$	A dummy identifying that project p is having DBE subcontracting requirements set by ODOT.
$PlanNumber_{pmt}$	The number of firms that purchase the plan for project p.

Table A2: Variables in Profit Function

		Π^1_{ijmt}	Π^2_{ijmt}
R^k_{ijmt}	$AuctionCompetition^k_{pmt}$	$PlanNumber_p$	$PlanNumber_p$
		$RivalLinkMax_{i,t-1}$	$RivalLinkMax_{j,t-1}$
	$MarketCompetition^k$	$ProjectValue_{m,t+1}$	$ProjectValue_{m,t+1}$
		$ProjectDBE_{pmt}$	$ProjectDBE_{pmt}$
C^k_{ijmt}	c^1_i/c^2_j	$log(Distance)_{ipm}$	$Log(Distance)_{jpm}$
		$log(Distance)_{jpm}$	$Log(Distance)_{ipm}$
		$log(SubAmount)_{i,t-1}$	$log(SubAmount)_{j,t-1}$
		$log(SubAmount)_{j,t-1}$	$log(SubAmount)_{i,t-1}$
		$log(Backlog)_{i,t-1}$	$log(Backlog)_{j,t-1}$
		$log(Backlog)_{j,t-1}$	$log(Backlog)_{i,t-1}$
		$ProjectDBE_{pmt}BidderDBE_i$	$ProjectDBE_{pmt}SubDBE_j$
		$ProjectDBE_{pmt}SubDBE_j$	$ProjectDBE_{pmt}BidderDBE_i$
		$SubEntrant_{jt}$	$SubEntrant_{jt}$
	c^1_{pmt}	$log(Cdays)_{pmt}$	$log(Cdays)_{pmt}$
		$log(EngEst)_{pmt}$	$log(EngEst)_{pmt}$
		$log(ItemNumber)_{pmt}$	$log(ItemNumber)_{pmt}$
τ^k_{ijmt}		$Network_{ij,t-1}$	$Network_{ij,t-1}$
		$NetworkSum_{ij,t-1}$	$NetworkSum_{ij,t-1}$
		$MetricDistance_{ij,t-1}$	$MetricDistance_{ij,t-1}$
		$DegreeCentrality_{i,t-1}$	$DegreeCentrality_{i,t-1}$
		$DegreeCentrality_{j,t-1}$	$DegreeCentrality_{j,t-1}$
		$HubCentrality_{i,t-1}$	$HubCentrality_{i,t-1}$
		$AuthCentrality_{j,t-1}$	$AuthCentrality_{j,t-1}$
		$log(Distance)_{ij}$	$log(Distance)_{ij}$

Notes: .