Testing for Bid Rigging in California Highway Construction

NEDKO YORDANOV, PHILLIP JOHNSON, AND ALEXANDER BERRY[1]

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[1] Economist, Managing Director and Senior Analyst, Econ One Research

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ABSTRACT: This paper examines California highway road resurfacing and construction auctions between 2000 and 2016 for evidence of bid rigging. Unlike much previous research on detecting bid rigging, we utilize methodologies that do not require a priori knowledge about the presence or nature of a conspiracy. We apply and extend the structural bid-rigging detection methodology of Bajari and Ye (2003) to the dataset to look for bid behavior that is consistent with collusion, specifically, we utilize two tests for decision-making patterns that appear inconsistent with independent firm behavior. Although test results suggest the presence of bid-rigging and identify specific firms as having suspicious bid and participation patterns, the methodologies are not sufficient to prove collusion. To limit false positives, we apply a filter requiring a firm's behavior be determined suspicious by both of our models. Our results indicate that some of the companies that participated in California highway road resurfacing and construction auctions may have engaged in shadow bidding, including the two largest: Granite Construction and Teichert Construction. Although these findings are not proof of bid-rigging, they suggest that a more thorough investigation is needed, both of the methodologies and of the companies that participate in California highway construction auctions.

I. Introduction

Bid rigging is one of the anti-competitive practices outlawed by Section 1 of the Sherman Antitrust Act. It occurs when two or more auction participants coordinate their bidding to increase their profits. This usually involves shading bids up (in procurement auctions) or down (in sales auctions). Both types seek to benefit the conspirators at the expense of the auction administrator; the former case increases procurement costs; the latter decreases auction revenues. Both types potentially introduce market inefficiency through a suppression of competition that may misallocate resources.

Highway construction procurement auctions have a history of auction participants conspiring to overcharge transportation agencies for construction projects.[2] These instances have prompted government transportation agencies to develop techniques to detect and battle such anticompetitive practices. However, some of their approaches are not ideal for the construction procurement setting. For example, the California Department of Transportation (Caltrans) screens for bid-rigging largely rely on statistical marker tests.[3]

[2] Joyner (1985), Porter and Zona (1993), Kawai and Nakabayashi (2014), and Imhof et al. (2018).

[3] California Department of Transportation, "Local Assistance Procedures Manual." Chapter 15, p. 10-11.

Although construction procurement auctions often involve substantially distinct projects, those techniques are most reliable in settings where similar products are repeatedly auctioned.[4] There are newer bid-rigging detection techniques seem more appropriate and reliable for construction procurement or other non-homogenous auction setting. Rather than look solely at placed bids and auction outcomes, these techniques examine differences between competitive bidders and probable conspirators in the way various factors affect bidding.

We created a data set of Caltrans highway construction auctions from 2000 to 2016. The data include bids, bidders, as well as project and bid-specific information. We analyze the data for statistical evidence of bid rigging. The methodologies are based on standard statistical regression techniques, which makes them prime candidates for addition to the analytical toolkits of government antitrust agencies.

The analysis uses two checks for non-competitive behavior: 1) pair-wise comparisons of company bidding behavior; and 2) by-company checks of whether bidding behavior is dependent on a firm's rank relative to another plausible colluder. The aim of each of these approaches is to distinguish colluders from other bidders under the presumption that after controlling for explanatory factors, evidence of the systematic differences between the bid behavior of colluding and non-colluding bidders will be observed.

Previous studies that applied multiple screening techniques have taken the set of conspirators identified by each test and considered the full list of colluders to be the union of those sets, i.e. firms that show collusion potential according to any of the tests.[5] In this paper we focus on the intersection of the sets identified by our bidding behavior tests, i.e. firms that show as potentially colluding in all bid determination tests. Although this may exclude some colluders from being identified, a conservative approach reduces the risk of false positives which might damage the reputation of a company and potentially lead to costly litigation or investigations.

Regression-based approaches have an advantage over statistical marker tests in that there is no homogeneity requirement for auctions. Statistics such as the average bid and the standard deviation of bids can be informative when homogenous items are auctioned periodically. For example, an increase in the average bid amount accompanied by a decline in the standard deviation is widely accepted as a sign of bid rigging. However, when the

[4] Both Abrantes-Metz et. al (2006) and Heijen et al. (2014) examine gasoline sales – a market for a homogeneous product.

[5] Bajari and Ye (2003) and Aryal and Gabrielli (2013).

auctions are of differentiated items, there may be a wide distribution of bids, making across-period comparisons uninformative.

An approach to homogenization that is available for highway construction auctions is to normalize all bids by the engineering estimates provided to bidders. Rescaling the auctions (dividing each bid by the engineering estimate) makes comparisons easier, though it does not eliminate auction-specific factors that may influence bid behavior.

We find statistical evidence that two of the largest companies' bidding appears inconsistent with a competitive bidding. These findings utilize an approach to bid rigging detection that is conservative in important respects. This study suggests—but does not prove—that the identified firms may have colluded to inflate procurement costs and doesn't preclude the possibility of the presence of additional conspirators.

II. Literature Review

The economic literature on bid rigging detection is largely divided into two main categories based on the adopted methodology – statistical marker or structural studies. The first approach focuses on bids and auction outcomes, relying exclusively on statistical metrics derived from bid data. The second method attempts to estimate the effect of explanatory factors on auction outcomes and identify bid-rigging by studying participants' behavior for deviations from competitive conduct.

Statistical markers were adopted in bid-rigging detection following Abrantes-Metz et. al (2006). The statistical screens developed in that paper have been widely adopted to identify indications of anticompetitive conduct in auctions. The methodologies use standard statistical measures such as averages and standard deviations, incumbency rates, and market share changes. Although useful, those techniques are restricted in their application to markets for homogenous or near-identical products. Imhof et. al (2016) describes the benefits of the statistical market approach when data is limited, though their study attempts to examine highly-differentiated projects in the Swiss highway construction auctions.

To overcome the limited sample size, Imhof et. al (2016) uses an arbitrary threshold to differentiate competitive and collusive conduct. While structural methods are more data intensive, testing the fit of data to models of competitive (and non-competitive) behavior allows the identification of non-competitive conduct to be done on the basis of statistically significant deviations from a well-specified model of competitive conduct rather than through an arbitrary threshold.

The most influential of the early papers to develop structural methodology for detecting anticompetitive conduct in auctions is Porter and Zona (1993). In that study the authors estimate parameters of an assumed bid distribution using bid ranks. They conjecture

that if bidding is competitive, there will be no statistically significant difference between parameters estimated using only winning or only non-winning bids. Porter and Zona (1999) proposes an alternative approach, which is to estimate the bid functions for firms that are assumed to be non-colluders. Then, they show that the predicted bids don't deviate significantly from the realized bids for these non-colluders, but there are statistically significant differences for the presumed colluding companies. The main limitation of these approaches is that neither provides a straightforward methodology to identify the set of colluders. The first approach detects the presence of phantom bidding but doesn't identify the entities engaged in that behavior. The second requires a priori identification of the colluders. Potentially, colluders could be identified by checking each possible set for anticompetitive behavior, however such a process becomes exponentially more time-consuming as the number of auction participants grows.

The methodology of Bajari and Ye (2003) identifies pairs of plausible colluders. The approach compares the effect of explanatory factors on auction participants' bids and examines the correlation between bidders' unexplained bid variation after controlling for these explanatory factors. The competitive hypothesis is that all bidders bid according to a bid function consisting of relevant explanatory factors, and bids will be independent across bidders after accounting for these factors. The paper examines an industry where the existence of collusion was not known. Their methodology doesn't rely on an ex-ante identification of colluding companies.

Kawai and Nakabayashi (2014) also develop a structural methodology to detect anticompetitive conduct in auctions. Their approach detects bid-rigging in repeated auctions. The Japanese highway construction auctions the authors examine have up to three rounds, where the latter two rounds occur if the lowest bid in the preceding round was above the secret reservation price. The authors find that the low bidders from the original round tended to maintain their ranking as lowest in later rounds while non-winning bidders were more likely to have a change in ranking. That suggested that high bidders were not competing against the low bidders. Chassang et. al (2017) prove that consistently isolated bids in an environment with coordination difficulties indicates the presence of an efficient collusion mechanism.

In addition to literature on bid rigging detection, research such as Pesendorfer (2000) and Harrington and Ye (2018) addresses the efficiency of the collusion mechanism. Chassang and Ortner (2018) study mechanisms which could weaken effective collusion schemes, such as the introduction of minimum prices. Asai, Kawai and Nakabayashi (2018) and Andreyanov, Davidson, and Korovkin (2017) research coordination between public agencies and private companies to capture public auctions.

The paper closest to our work is Aryal and Gabrielli (2013) which searches for collusion in Caltrans auctions from 2002 to 2008 following the methodology of Bajari and Ye (2003) by testing for bid symmetry and independence. Similar to the results in this paper, they find evidence of collusion. However, our paper differs from Aryal and Gabrielli (2013) not only in the data period we examine (we study Caltrans data from 2000 to 2016), but also in how we utilize the Bajari and Ye (2003) methodology and in our second stages of the collusion detection mechanism. Aryal and Gabrielli (2013) uses the union of pairs identified as plausible colluders in each Bajari and Ye test and then applies their own non-parametric cross-company collusion detection screen. Their non-parametric screen assumes colluding firms bid higher than non-colluding firms and thus, colluding firms' implied costs (inferred from their bids) will be higher than those of non-colluding firms. They thus check whether the plausibly colluding firms' implied cost distribution stochastically dominates that of the firms that they have categorized as not plausible colluders. We do not use their non-parametric cross-company collusion detection screen because its main assumption seems too strong. Colluding firms do not need to bid higher when placing cover bids so long as they bid above the designated cartel low bidder. Instead, we take a more conservative approach with the Bajari and Ye tests, requiring that pairs are identified as suspicious by both tests, and add our own check for collusive behavior that looks for suspicious changes in conduct company-by-company.

Other research related to Caltrans highway construction procurement includes Krasnokutskaya and Seim (2011), which examines the effect of small business subsidies in the Caltrans auctions on company entry decisions and auction outcomes. Balat, Komarova, and Krasnokutskaya (2017) explore the impact of ex-ante subcontracting rules. Their conclusion is that although ex-ante subcontracting increases the competitiveness of contractors' bids it may lead to less aggressive pricing from the subcontractors.

This paper follows and expands the literature on bid-rigging conspiracy detection. Our work examines the largest dataset of U.S. highway construction procurement auctions to date both in terms of years covered, number of auctions, number of participants, and total cost of construction work. In addition to applying more restrictive conditions on the interpretation of analysis results, we have developed a test for bidding consistency of individual companies. We are the first study, to the best of our knowledge, to identify plausible colluders which consistently fail all proposed tests for competitive conduct in an environment with no prior knowledge of collusion.

III. Institutional Background

A. Caltrans Highway Construction Procurement

Caltrans uses procurement auctions to allocate highway construction contracts. The auctions are first-price sealed-bid auctions and only bids submitted up to a certain deadline are considered. The company with lowest bid (after preference adjustments) is the auction winner. Only qualified registered contractors are eligible to bid, and each can submit only one bid. Limited bid corrections are allowed once all bids are revealed. If there are multiple lowest bids, bids submitted by California-based companies receive preference.

When ranking bids, Caltrans adjusts down by 5% (for purposes of deciding the low bidder) the bids of Small-Business Enterprises (SBEs) and Disabled Veteran Business Enterprises (DVBEs). Projects may require a portion of the final bid to be subcontracted to SBEs or DVBEs. If so, any bid that doesn't meet the minimum threshold is considered ineligible. Firms may also be disqualified if on previous projects they went over-budget, misrepresented themselves as a SBE or a DVBE, or subcontracted more than 10% of the total bid to a single subcontractor.

To guarantee the project has been performed to Caltrans specifications, projects specify individual elements. Some of these tasks occur so often in projects that they are standardized, while others are project-specific. When submitting a bid, bidders are asked to submit an estimate for each of these items rather than a total lump-sum bid. The total of individual items is the final bid.[6]

The bidding process usually takes three to eight months, though a protest of the results may delay awarding the contract for one to three months. The contracting process begins with the issuance of a Notice to Bidders and Special Provisions, which is an outline of the project's specifications. Among other project characteristics, the document lists all individual project items, Caltrans' requirement for the percentage of the final bid that must be performed by SBEs or DVBEs, the contract duration, and the opening date for bidding. Highway construction procurement auctions are noticed three to seven weeks prior to the bid opening, the length depending on the project's complexity and the time of the year.[7]

After the advertising period, interested parties submit bids. All bids are opened at the time specified in the Notice to Bidders. After confirming participants are eligible, Caltrans determines the lowest bid and issues a Notice of Intent to Award. At that point any of the

[6] In more recent bids, firms are required to submit the list of tasks for which each subcontractor is responsible, in addition to the full list of subcontractors.

[7] Weeks containing federal holidays are usually not counted towards the advertising period.

non-winning bidders can protest the process, bringing forward a case for why the winning bidder should not be awarded the project. After disputes are settled, Caltrans negotiates the final contract with the winning contractor. The timeframe for reaching an agreement is 30 days for projects up to $200 million, and 60 days for contracts over $200 million. If no contract is reached, Caltrans may issue Notice of Intent to Award to the second highest bidder. Caltrans is not required to award a contract at the end of the negotiation process. If none of the auction participants agree to a contract, the agency may re-administer the auction or cancel it.

In addition to specifying items of the construction project, Caltrans attempts to ensure performance by limiting the eligibility of prospective bidders. Participation is restricted to construction companies which are registered with the agency and have met project specific certification requirements.

In the period between 2000 and 2016, Caltrans administered over 8,000 auctions and the total value of the projects awarded was over $37 billion. The average winning auction bid was around $4.5 million, though project costs could run as high as $1.4 billion.

B. Bid rigging

The public benefits from competition between contractors by paying less for the same services. However, aggressive bidding by participants results in low profit margins. Bid-rigging in procurement auctions would be a way for participants to increase and stabilize profit margins. Effective bid-rigging increases the procurement costs to the taxpayers who ultimately finance public procurement.

There are three techniques for bid-rigging that may be used individually or in combination: bid suppression, cover (phantom) bidding, and bid rotation. Bid suppression is when companies avoid bidding in auctions where other colluders are present which allows the participating colluder to inflate its bid. Cover bidding occurs when all co-conspirators (except one) submit bids that are designed to lose to a specific co-conspirator's bid. This creates an appearance of more competition than actually exists. Bid rotation is a practice in which conspirators alternate which co-conspirator is designated to win an auction. This last practice is generally combined with either bid suppression or cover bidding.

The high individual auction costs coupled with the limits on participation enhance conditions for bid rigging. In addition to the increased costs to the public, there are other dynamic effects of bid rigging on Caltrans highway construction procurement auctions. Artificially inflated procurement costs may lead to higher engineering estimates in the information provided with project announcements. The Office Engineer relies on past procurement costs when calculating the engineering estimate for each auction. Consequently,

if artificially inflated costs increase the estimates and competing bidders use the estimates in forming their bids, even auctions that are not subject to bid-rigging may have somewhat inflated procurement costs.

IV. Methodology

It is more challenging to find an acceptable competitive benchmark for auctions of heterogeneous items such as construction projects. Accordingly, bid rigging cases identified through statistical markers tend to involve goods or services that are re-auctioned regularly or in multiple geographic areas. In such cases there may be times or locations that are free of collusive activity. If the items in two sets of auctions (competitive and anticompetitive) are sufficiently similar, valid comparisons can be made; if the auctions are of very different items or held irregularly, that is likely not informative.

Normalizing project bids with Caltrans' project-specific cost estimate (the "engineering" estimate) can address project heterogeneity. However, as noted above, the relationship of engineering estimates to true project costs can change over a period of examination if, for example, a cartel starts to influence bidding. Statistical marker approaches look for increases in average bids accompanied by decreases in the standard deviation of bids. If engineering estimates are elevated it would decrease normalized bids, hindering collusion detection through statistical markers. Thus, statistical marker tests may miss anticompetitive behavior in settings like the Caltrans highway construction auctions. Rather than focusing on statistical markers in auction outcomes, our methodology looks for deviations from competitive behavior.

The analysis covers 2,356 contracts with 544 distinct contractors, each of whom placed a bid for at least one project. Most of the contractors bid in only a few auctions and seem implausible conspirators. We restrict the set of firms to be analyzed to those which have interacted with any other contractor at least 3 times per year on average. This approach leaves 46 companies to be part of the analysis. All the plausible colluders are listed in Table 1. The rest of the companies are aggregated under a common umbrella and are considered to act uniformly, i.e. they bid according to a common bid function.

Table 1
List of Companies to be Examined for Collusive Behavior

00000008	Teichert Construction	00579845	Emmetts Excavation
00000022	Pavex Construction Division	00591940	R G W Construction
00000088	Griffith	00592597	Top Grade Construction
00000089	Granite Construction	00593393	Sierra Nevada Construction
00091712	Baldwin Contracting	00644515	Ghilotti Construction
00105709	Mercer Fraser	00676166	J A Gonsalves And Son Construction
00116307	Security Paving	00684075	Qualcon Contractors
00132128	Ghilotti Bros	00688659	Excel Paving
00140069	Skanska Usa Civil West California District	00704195	De Silva Gates Construction
00149783	Matich	00709237	Vintage Paving
00171432	Argonaut Constructors	00726454	Martin Brothers Construction
00201696	Ogrady Paving	00743775	Highland Construction
00211337	George Reed	00747612	Sully Miller Contracting
00238650	Bay Cities Paving And Grading	00750542	Hazard Construction
00264193	R Burke	00753630	Ron Hale Construction
00267073	All American Asphalt	00754230	Steve Manning Construction
00282929	Lees Paving	00759729	O C Jones And Sons
00295418	Tullis	00767055	Papich Construction
00357560	North Bay Construction	00769989	J F Shea Construction
00388077	Tom Mayo Construction	00772589	Flatiron West
00414567	Vance	00776848	Windsor Fuel
00471473	W Jaxon Baker	00782908	R J Noble
00523019	Union Asphalt	00897282	Cruconstruction Group

A. Suspicious Behavioral Relationships Across Bidders

We look at suspicious behavioral relationships across bidders using methods introduced by Bajari and Ye (2003). They argue that, in a competitive setting, explanatory factors (such as capacity constraints, costs, and rival characteristics) should be able to explain all correlation in companies' bids. I.e., the residuals to an OLS regression of normalized bids on the relevant factors should be uncorrelated for competing companies. This forms the basis for a "conditional independence" test for collusion. They also hypothesize that the explanatory factors of non-colluding companies will have a common relationship to their bids but there won't be a common relationship for colluding companies. Bajari (2001) proves that under competition there should be no effect on a non-colluding company's bid function if its identity is changed. Bajari and Ye (2003) expands on this idea to show that if two companies are treated as a single entity, it shouldn't affect the estimate of their bids' relationship to explanatory factors if both bidders are acting competitively. Conversely, if two colluding companies are treated as a single entity, the presence of anticompetitive conduct should alter the estimated bid function from their separately estimated bid functions. This forms the basis for a second test for collusion, the "exchangeability" test. Thus, their methodology provides two hypothesis tests.

The model for companies' bids is:

$$\begin{aligned} &Normalized\ Bid_{i,t} \\ &\quad = \alpha_i + \beta_{1,i} Utilized\ Capacity_{i,t} \\ &\quad + \beta_{2,i} \log\left(Distance\ to\ Project\ Site_{i,t}\right) \\ &\quad + \beta_{3,i} \max\left(Available\ Capacity_{-i,t}\right) \\ &\quad + \beta_{4,i} \min\left(\log\left(Distance\ to\ Project\ site_{-i,t}\right)\right) + \tau_t + \varepsilon_{i,t} \end{aligned}$$

This model is essentially the same model proposed by Bajari and Ye (2003) except that the buyers concentration of work in the project region is excluded (all projects are within one state, California).[8] $Normalized\ Bid_{i,t}$ is the ratio of the placed bid placed by company i in auction t and the engineering estimate for auction t, α_i and τ_t are respectively company and auction fixed effects, and $\beta_{1,i}$, $\beta_{2,i}$, $\beta_{3,i}$ and $\beta_{4,i}$ are the effects of explanatory factors for company i. The utilized capacity variable is the dollar amount of work auctions for which the contract duration has not expired, i.e. the work in progress (WIP), as a fraction of the maximum WIP during the calendar year. The distance to the project is calculated using the address provided by the bidder and the midpoint of all construction locations associated with the contract. The available capacity is the difference between the maximum annual WIP and current WIP as a share of the maximum annual WIP. The notation $-i,t$ relates to all auction rivals of company i in auction t, so $\beta_{3,i}$ and $\beta_{4,i}$ are the effect of rival firm characteristics on company i's bids.

Conditional independence holds for bids by a pair of companies (i,j) if

$$cor\left(\varepsilon_i, \varepsilon_j\right) = 0$$

where ε_i and ε_j are the vectors of residuals for all auctions where both companies bid. Exchangeability holds for a pair of companies (i,j) if

$$\beta_{1,i} = \beta_{1,j}, \beta_{2,i} = \beta_{2,j}, \beta_{3,i} = \beta_{3,j}, \beta_{4,i} = \beta_{4,j}$$

The analysis model allows bidder heterogeneity through individual company fixed effects while assuming a common relationship to explanatory factors for firms behaving competitively.

A limitation is that omitted explanatory factors may lead to unexplained correlation in bids that is not due to collusion. This implies one should not interpret positive results from these tests as proof of collusion. As has been discussed elsewhere, it is important to utilize other methods that would alleviate the issues created by this limitation.

[8] This is the same specification as in Aryal and Gabrielli (2013).

B. Suspicious Behavioral Inconsistency Within a Company

The Bajari and Ye (2003) methodologies examine pairs of firms for signs of collusive behavior. With their exchangeability test in particular, a positive result (collusion plausible) may be driven by just one of the pair having colluded. As an additional filter to the extent to which companies are identified as plausible colluders, we propose a test which checks companies individually for indications of bid rigging.

The intuition is similar to that of the exchangeability test: colluding firms will sometimes bid to win and sometimes place cover bids, while firms that do not collude always bid to win. If just the bids of cartel members are examined, the lowest bid submitted by cartel members considers both its costs and the potential for competitive bidding from non-cartel bidders. Other bids by cartel members are likely to be cover bids, i.e. not intended to win. A cartel member's bid that is not directed towards winning will not be chosen in the same manner as when it is intended to win. Thus, each cartel member may bid according to one bid function when they are the designated competitive auction bidder within the cartel and according to another bid function when they are not. Whereas the exchangeability test looked for differences between the estimated bid functions of company pairs, this test looks for alterations in a company's own bid function given the rank of its bid relative to those of other bidders who may be co-conspirators.

This suggests checking whether each plausible cartel member behaves differently when their bid is the lowest among other cartel members than when it is not. How can you test a company for suspicious bidding behavior relative to a set of co-conspirators without already having identified the set of possible conspirators? It may be difficult to test every possible cartel. However, it is relatively straightforward to check each company within pairs of plausibly-colluding firms for differences in the role of explanatory factors when their bid is the lower bid within the pair and when it is not. Then, we can apply the findings of this analysis to the results of the pair-wise bidding behavior analysis.

Assuming a plausible colluder's bid is a cover bid only when it's the highest bid among a pair of plausible colluders misidentifies some bids as non-cover bids. Pairwise comparison of bids ignores that the cartel may have included another bidder, not in the comparison pair, who submitted the non-cover bid. Thus, the low bids among pairs of prospective colluders may be a mix of cover and non-cover bids, while the high bids would contain only cover bids if both companies are colluding. So, the true differences that would arise from comparing cover and non-cover bids is likely larger than the differences between the high bids placed by the pair of companies being examined and other bids. This implies a bias in the test against finding evidence in support of collusion.

For every pair of bidders (A, B) designated as plausible colluders by our suspicious behavior across companies analysis:

$$
\begin{aligned}
&Normalized\ Bid_{i,t} \\
&\quad = \alpha_{1,i} + \beta_{1,i} Utilized\ Capacity_{i,t} + \beta_{2,i} Distance\ to\ Project_{i,t} \\
&\quad + \beta_{3,i} \max\left(Available\ Capacity_{-i,t}\right) \\
&\quad + \beta_{4,i} \min\left(Distance\ to\ Project_{-i,t}\right) \\
&\quad + \alpha_{2,i} \text{Company A higher bid}_{i,t} \\
&\quad + \beta_{5,i} Utilized\ Capacity_{i,t} * \text{Company A higher bid}_{i,t} \\
&\quad + \beta_{6,i} Distance\ to\ Project_{i,t} * \text{Company A higher bid}_{i,t} \\
&\quad + \beta_{7,i} \max\left(Available\ Capacity_{-i,t}\right) * \text{Company A higher bid}_{i,t} \\
&\quad + \beta_{8,i} \min\left(Distance\ to\ Project_{-i,t}\right) * \text{Company A higher bid}_{i,t} \\
&\quad + \alpha_{3,i} \text{Company B higher bid}_{i,t} \\
&\quad + \beta_{9,i} Utilized\ Capacity_{i,t} * \text{Company B higher bid}_{i,t} \\
&\quad + \beta_{10,i} Distance\ to\ Project_{i,t} * \text{Company B higher bid}_{i,t} \\
&\quad + \beta_{11,i} \max\left(Available\ Capacity_{-i,t}\right) * \text{Company B higher bid}_{i,t} \\
&\quad + \beta_{12,i} \min\left(Distance\ to\ Projec_{-i,t}\right) * \text{Company B higher bid}_{i,t} \\
&\quad + \tau_t + \varepsilon_{i,t}
\end{aligned}
$$

The indicator variables $\text{Company A higher bid}_{i,t}$ and $\text{Company B higher bid}_{i,t}$ take the value 1 when company i is A or B (respectively) and its bid in auction t is the highest bid among the pair. The indicators equal 0 in all other cases including when only one of the companies is present in an auction. Thus, if companies A and B are not part of a cartel, the estimates would satisfy the following condition

$$\alpha_{2,i} = 0, \beta_{5,i} = 0, \beta_{6,i} = 0, \beta_{7,i} = 0, \beta_{8,i} = 0,$$
$$\alpha_{3,i} = 0, \beta_{9,i} = 0, \beta_{10,i} = 0, \beta_{11,i} = 0, \beta_{12,i} = 0$$

V. Data

We collected data from the Caltrans auction data repository covering highway construction and maintenance procurement auctions from 2000 to 2016.[9] For each project the data included the Caltrans region (numbered 1-12), California county where the project is located, state road or highway number along with exact mileposts defining the stretch of road for pavement or resurfacing. The project data also includes 1) expected project duration, 2) project items or requirements (project items are classified by the scope of work to which they relate, i.e. building construction, drainage facilities, surfacing and pavements, etc.), 3) the project cost estimate by the Office of Engineer, 4) date on which all submitted bids are open, 5) an identifying contract number, and 6) DBE requirements. The data on the

[9] The details for every project offering are contained in individuals PDF files which were downloaded and scraped to extract relevant data.

bidders and the auction outcome include 1) number of proposals issued, 2) number of bidders, and 3) bidder information. Bidders are described by the contractor license number, name, address, and phone numbers. For each individual bid submitted by the auction participants, breakdowns by individual bid components are reported in addition to the total bid amount.

There are 8,503 auctions included in the data we obtained. 265 auctions were dropped because data could not be extracted. Another 16 auctions were removed because they were cancelled, postponed, or received no bids, 6 because of missing project locations and contractor license number, and 11 due to the presence of joint ventures.[10] The focus of this paper is highway pavement and resurfacing with at least 2 bidders, so 5,756 projects were dropped from the sample because highway pavement and resurfacing doesn't account for majority of the project in dollars or there was a single relevant bid. Finally, 93 projects are removed from the sample as project distances could not be determined. This left 2,356 auctions with more than 12,000 bid submissions; 544 unique bidders of which 239 won at least one project; and total project costs of $7.7 billion as presented in Table 2.

Table 2
Project Auction Characteristics

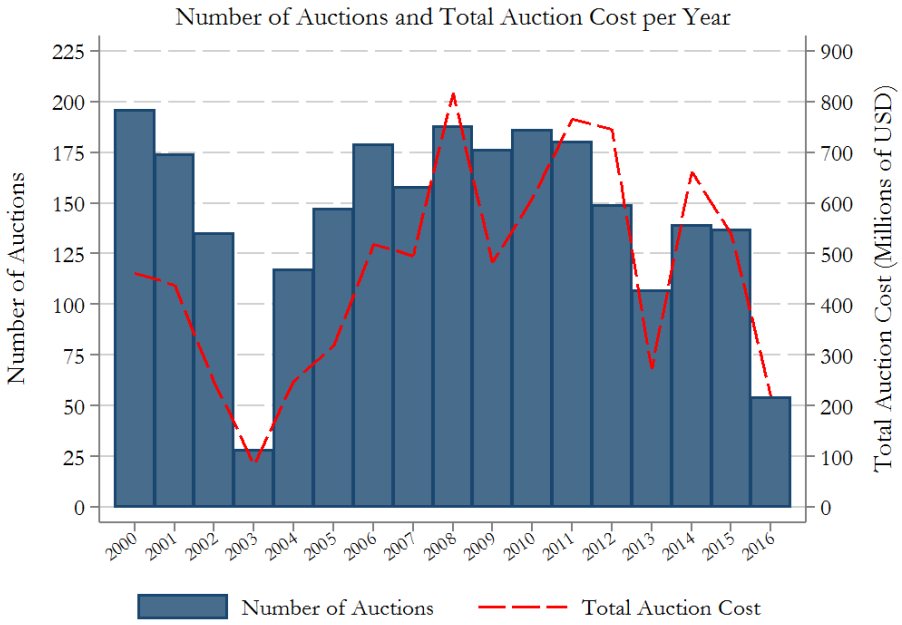
Number of auctions	2356
Number of submissions	12041
Number of unique bidders	544
Number of unique auction winners	239
Total amount of auction winning bids (in USD million)	$7,692

As shown in Figure 1 the number of auctions, as well as Caltrans' total project costs, vary from year to year. In most years, Caltrans offered at least 125 pavement and resurfacing focused projects, though never more than 200. Total costs are closely related to the number of projects. Most notable in the chart is an apparent slump in 2003, however that is likely due to the lack of project records from Caltrans for the entire first half of the year.[11]

[10] Joint ventures use the contractor license number of one of the contractors involved in the venture. That erroneously assigns the joint venture conduct to a single contractor. Additionally, auctions which require the presence of joint ventures are usually outliers in terms of project complexity, so they are removed from the sample.

[11] Contract information from the first half of 2003 is no longer available through Caltrans. For that reason other Caltrans studies explore data before or after that period, or as Bajari, Houghton, and Tadelis (2014) omit it from their sample.

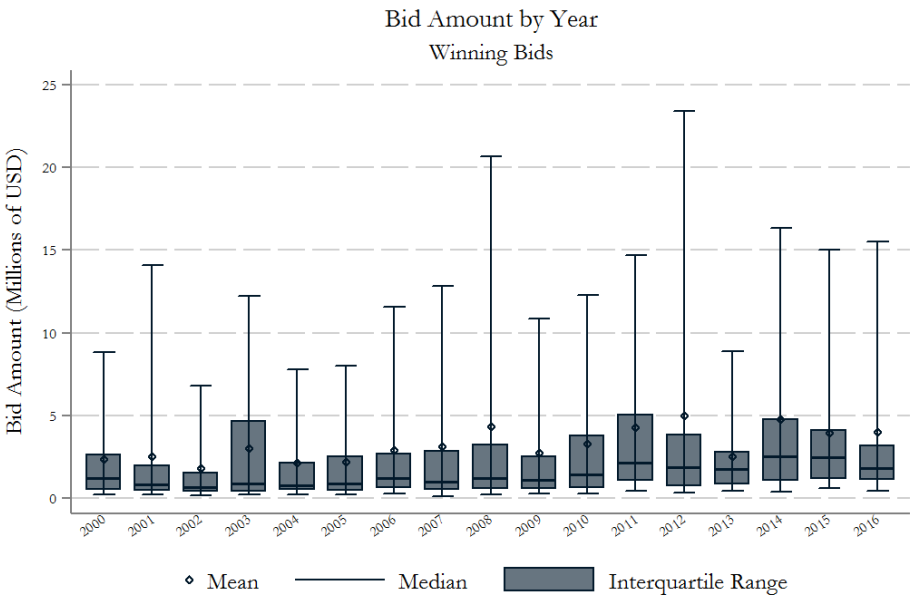
Figure 1



Source: Caltrans Auction Data.

The annual average cost of projects ranged between $2 and $5 million (though the median was somewhat lower, ranging between $1 and $3 million). Figure 2 shows that the difference between mean and median figures of $2 million is driven primarily by outliers with the 95th percentile project costs in the $7 million to $24 million range. About 75% of all pavement and resurfacing projects cost less than $5 million. The bid distributions, presented in Figure 3, reflect the inclusion of higher (losing) bid levels, though the figures remain similar. Normalizing the bids, through dividing each bid by the engineering estimate for the respective project, reveals a more symmetric distribution, clustered near 1. Figure 4 shows the distribution of the normalized winning bids, which range between .5 and 1.5 for 90% of observations across all years. Figure 5 shows the distribution for all normalized bids. As with Figure 3, the bid levels are higher though the distributions remain similar. These figures show the variability in nominal bids which complicates comparison across auctions.

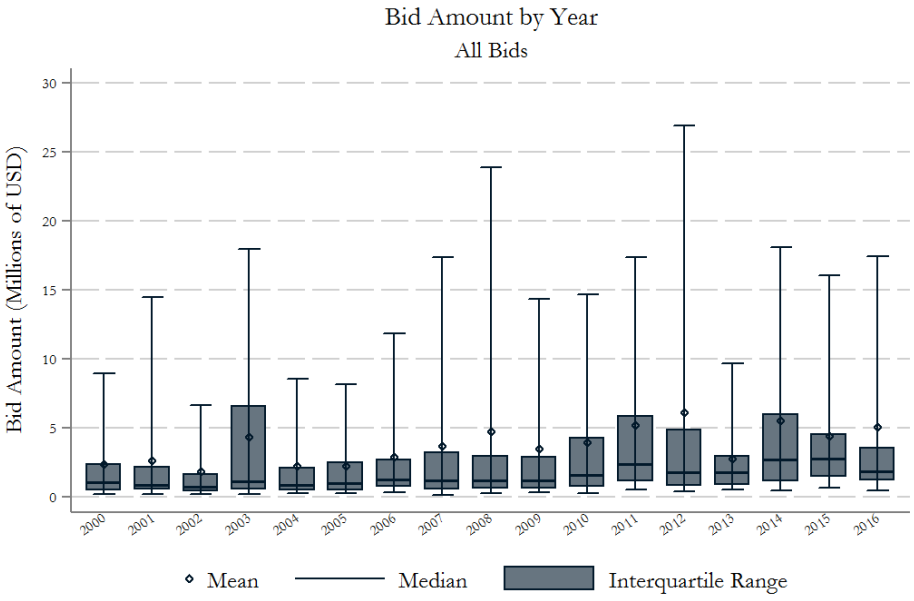
Figure 2



Note: Whiskers denote the 95th and 5th percentile upper and lower bounds, respectively.

Source: Caltrans Auction Data.

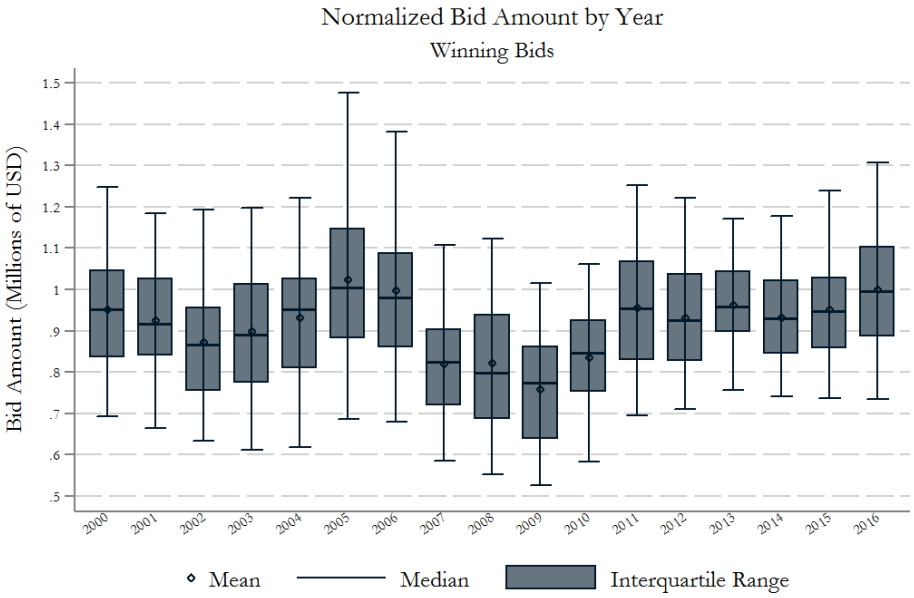
Figure 3



Note: Whiskers denote the 95th and 5th percentile upper and lower bounds, respectively.

Source: Caltrans Auction Data.

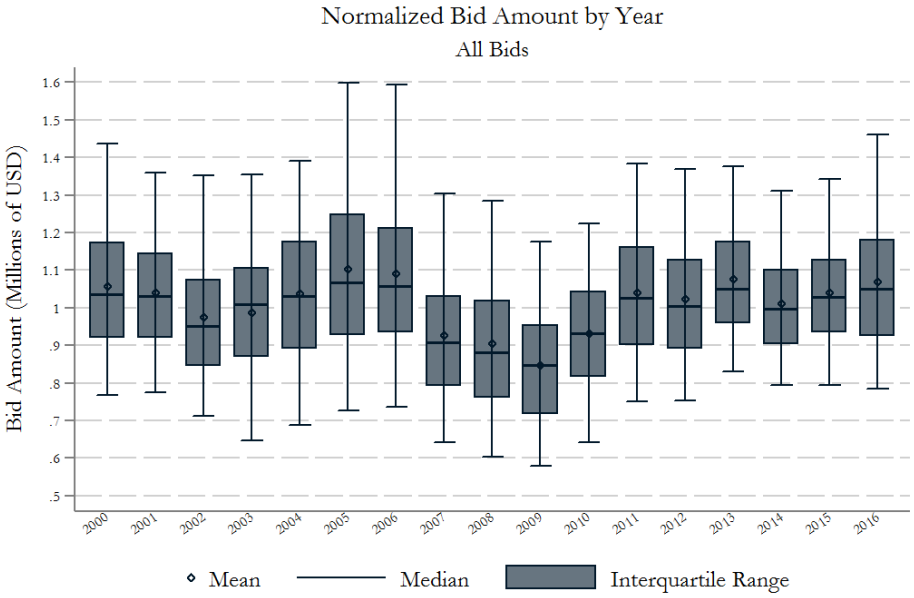
Figure 4



Note: Whiskers denote the 95th and 5th percentile upper and lower bounds, respectively.

Source: Caltrans Auction Data.

Figure 5



Note: Whiskers denote the 95th and 5th percentile upper and lower bounds, respectively.

Source: Caltrans Auction Data.

As described in section IV, there are 46 individual entities that this analysis considers as plausible bid-rigging conspirators. Among those entities, the top 10 companies account for almost half of all public highway pavement and resurfacing spending regardless of which

sorting metric is used. Three options are presented in Table 3 through Table 5: number of auctions participated, number of auctions won, and total winning bids (respectively). Regardless of the exact ordering mechanism, five companies are always present: Granite Construction (00000089), Teichert Construction (00000008), George Reed (00211337), W Jaxon Baker (00471473), and All American Asphalt (00267073). Four of these companies are headquartered in Northern California, All American being the sole Southern California contractor.

Table 3
Top 10 Companies by Total Number of Auctions Participated

Contractor License No	Auctions Participated	Auctions Participated as Share of All Auctions	Auctions Won	Auctions Won as Share of All Auctions	Total Winning Bid Amount million USD	Winning Bids as Share of All Auction Revenues
(1)	(3)	(4)	(4)	(5)	(6)	(7)
00000089	1,486	63.1 %	413	17.5 %	$ 1,427.10	18.6 %
00000008	433	18.4	110	4.7	421.64	5.5
00211337	277	11.8	91	3.9	215.89	2.8
00471473	230	9.8	63	2.7	163.07	2.1
00091712	226	9.6	48	2.0	138.77	1.8
00747612	222	9.4	36	1.5	125.48	1.6
00267073	217	9.2	112	4.8	219.72	2.9
00000022	201	8.5	54	2.3	156.10	2.0
00726454	197	8.4	12	0.5	33.34	0.4
00704195	188	8.0	31	1.3	328.47	4.3
			970	41.2 %	3,229.58	42.0 %

Table 4
Top 10 Companies by Total Number of Auctions Won

Contractor License No	Auctions Participated	Auctions Participated as Share of All Auctions	Auctions Won	Auctions Won as Share of All Auctions	Total Winning Bid Amount million USD	Winning Bids as Share of All Auction Revenues
(1)	(3)	(4)	(4)	(5)	(6)	(7)
00000089	1,486	63.1 %	413	17.5 %	$ 1,427.10	18.6 %
00267073	217	9.2	112	4.8	219.72	2.9
00000008	433	18.4	110	4.7	421.64	5.5
00211337	277	11.8	91	3.9	215.89	2.8
00471473	230	9.8	63	2.7	163.07	2.1
00105709	163	6.9	56	2.4	140.03	1.8
00000022	201	8.5	54	2.3	156.10	2.0
00295418	129	5.5	49	2.1	129.29	1.7
00091712	226	9.6	48	2.0	138.77	1.8
00523019	124	5.3	45	1.9	98.50	1.3
			1,041	44.2 %	3,110.12	40.4 %

Table 5
Top 10 Companies by Total Winning Auction Bid Amounts

Contractor License No	Auctions Participated	Auctions Participated as Share of All Auctions	Auctions Won	Auctions Won as Share of All Auctions	Total Winning Bid Amount (million USD)	Winning Bids as Share of All Auction Revenues
(1)	(3)	(4)	(4)	(5)	(6)	(7)
00000089	1,486	63.1 %	413	17.5 %	$ 1,427.10	18.6 %
00000008	433	18.4	110	4.7	421.64	5.5
00759729	161	6.8	36	1.5	394.57	5.1
00704195	188	8.0	31	1.3	328.47	4.3
00267073	217	9.2	112	4.8	219.72	2.9
00238650	145	6.2	26	1.1	216.26	2.8
00211337	277	11.8	91	3.9	215.89	2.8
00116307	122	5.2	38	1.6	191.71	2.5
00471473	230	9.8	63	2.7	163.07	2.1
00140069	144	6.1	32	1.4	156.91	2.0
			952	40.4 %	3,735.34	48.6 %

Table 6 summarizes the values of the independent variables across the 12,041 observations used below to examine the competitiveness of auction participants' conduct.

Table 6
Auction Participant Characteristics Summary

	Mean	Minimum	1st percentile	Median	99th percentile	Maximum
	(1)	(2)	(3)	(4)	(5)	(6)
Average Distance to Project	111.71	0.31	3.38	63.02	558.59	2,863.35
Backlog (millions of USD)	31.44	0.00	0.00	1.91	286.85	502.03
Capacity (millions of USD)	68.27	0.07	0.45	19.95	414.64	1,172.12
Capacity Utilization	0.23	0.00	0.00	0.10	0.91	1.00
Log(Average Distance)	4.17	0.27	1.48	4.16	6.33	7.96
Maximum Rival Excess Capacity	0.97	0.06	0.39	1.00	1.00	1.00
Minimum Rival Log(Average Distance)	3.32	0.27	0.96	3.35	5.64	6.70
Contract Duration	92	7	15	50	565	1,050
Engineering Estimate (millions of USD)	4.00	0.09	0.16	1.31	46.05	89.73
Proposal Plans Issued	12	2	3	11	38	59

As Table 6 shows, the maximum average distance from a company headquarter to a project is 2,863 miles. The road distance from Pelican State Beach in the northwestern corner of California to Winterhaven in the southeastern corner is 1,015 miles. That suggests that no distance should be larger than a thousand miles. However, some companies are based out of state. The extreme example is Surface Preparation Technologies Inc. based in Mechanicsburg, PA, over 2,800 miles from the Monterey county project it bid on in 2004. The company did not win the single auction in which it participated. Indeed, 99% of all bids are placed from companies located within 560 miles of the project site, consistent with the

hypothesis that only companies reasonably close to the project location would be capable of placing a competitive bid.

Note that the projects included in the analysis involve both resurfacing and pavement. Building a stretch of highway from the ground up is a time-consuming process. The lengthiest project involved the reconstruction of a twelve-mile stretch of four-lane highway between Sacramento and El Dorado Hills. This project required 1050 days, almost 3 years, to complete. Given the commitment the project required, only two companies placed bids – Granite Construction and Teichert Construction, two of the most prominent contractors in California.

A substantial portion of the auctions are not analyzed because they are not paving and resurfacing projects and many bidders are not tested (given that they are a priori considered to not be plausible colluders based on their insufficiently frequent bidding). However, information from all bidders and auctions is utilized in the backlog and capacity calculations. The largest backlog calculated from the data is over $500 million, while the total project amount collected by Granite Construction, the largest bidder, is just $1,500 million. That suggests that most of Granite's projects are concentrated within a narrow time frame. That is not the case. The large backlog is due to having non-paving-and-resurfacing projects included in the backlog and capacity calculations for completeness. Ultimately, backlog and capacity values enter the cost functions only through their ratio, which is the capacity utilization.

VI. Bid Rigging Detection

Using a restricted model in which we pool the effects of plausible and implausible colluders, we verify that the Bajari and Ye (2003) specification fits the Caltrans auctions. The theoretical framework predicts that bids would increase whenever any of the explanatory factors increases. The results from the estimation are presented in Table 7. While we observe a positive relationship between bids and own and rival project distance, as well as maximum rival available capacity, our estimation predicts that bids would fall as a company reaches its capacity constraint.

Table 7
Common Impact Regression Results

Variable	Coeff.	T-stat.	P-val.
(1)	(2)	(3)	(4)
Log(Project Distance)	0.0198 ***	10.654	0.000
Capacity Utilization	-0.0130 **	-2.220	0.026
Min(Rival Project Distance)	0.0135	0.810	0.418
Max(Available Capacity)	0.0024	0.641	0.522
Bidder Fixed Effects	YES		
Observations	12041		
Adj. R-squared	0.716		

Note: *** Significant at 1% level; ** Significant at 5% level;
* Significant at 10% level.

We test the 46 companies in Table 1 for evidence of suspicious bidding in the Caltrans highway construction procurement auctions. First, we perform the Conditional Independence and Exchangeability tests for evidence of cross-company behavioral anomalies. Next, we check whether the bid ranking (a pair of potentially colluding companies) impacts how explanatory factors affect a firm's bid function. All these approaches test hypotheses that non-colluding companies do not have such variations in their bid functions and interpret the finding of such effects may be a symptom of phantom bids to cover collusive behavior, i.e., bid rigging.

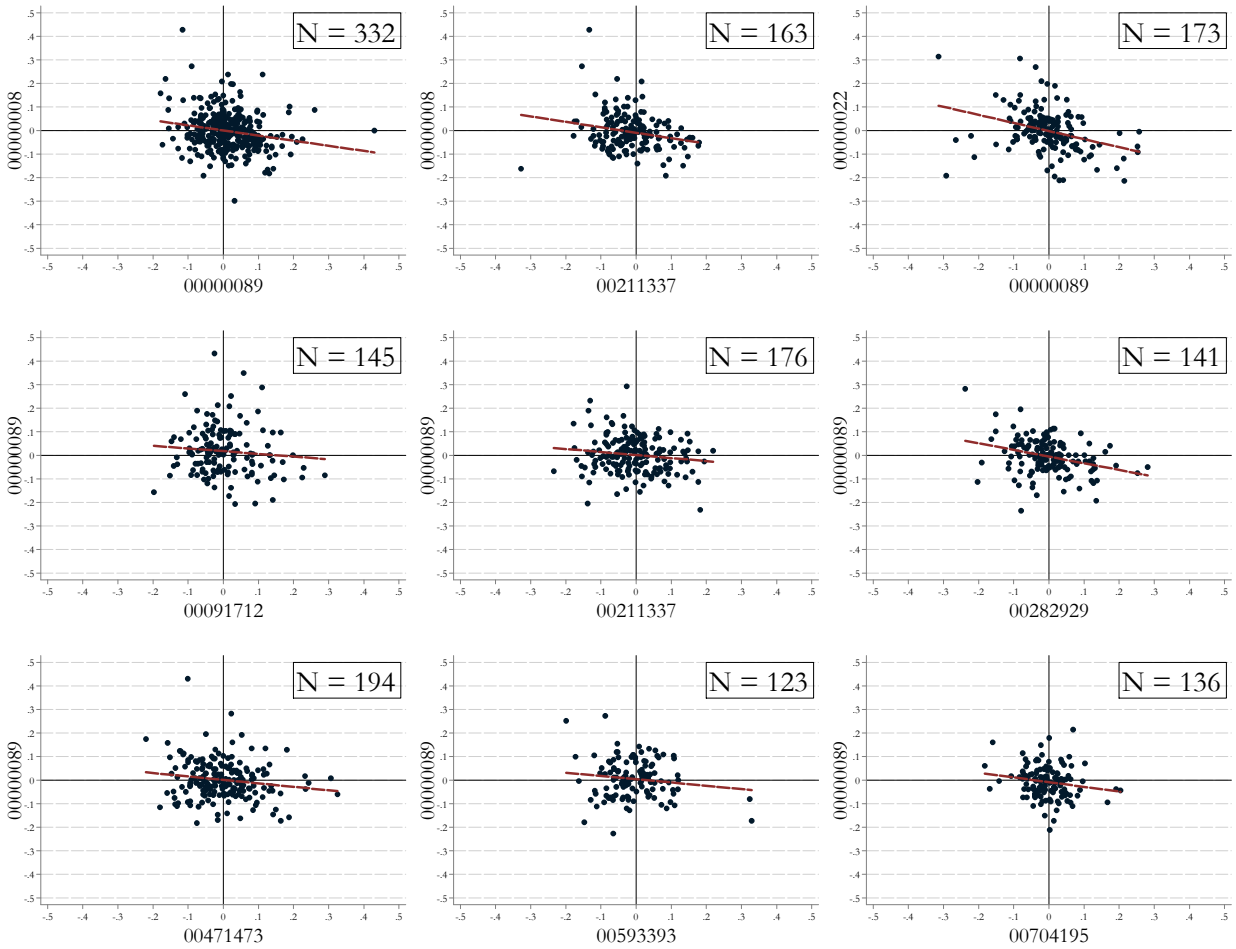
From the 46 companies, there are 562 pairings present in the auction data. About a third of those pairs (165) don't participate in more than three auctions, the minimum required to conduct the Conditional Independence test. The Conditional Independence and Exchangeability tests are performed on the remaining 397 pairs. Of these, 243 pairs participated in auctions less than 3 time a year on average (for years in which the companies interacted in an auction) – a threshold established to differentiate plausible colluders from other bidders. Results for the remaining 154 pairs are reported in the appendix in Table 9. The table shows there are pairs that fail one of the tests, both, or neither. At the 95% confidence level there are 47 pairs which fail the Conditional Independence test and 32 pairs fail the Exchangeability test. Combining the results of the two tests yields a set of 13 pairs which fail both tests. These pairings, listed in Table 10, include 16 of the 46 companies from Table 1.

Figure 6 displays the regression residuals for the nine pairs of companies which have participated in auctions together most often. Of those firm-pairs, six fail the conditional independence test: (00000008,00000089), (00000008,00211337), (00000022,00000089), (00000089,00282929), (00000089,00471473), (00000089,00704195). As evident from the

charts, the company-pairs which do not fail the test tend to be more closely clustered around the origin and have correlations close to zero.

Figure 6

Regression Residuals Correlation



The results from the tests are reported in Table 11. The table examines the statistical evidence that one of the companies, both, or none exhibited differences in bidding behavior. For every company pair, three values are reported: one p-value for each the tests of whether a company's coefficient differences were zero, and a combination of the two p-values for the pair. The combination of the two p-values can be interpreted as the strength of the evidence from this test that both companies are plausible colluders (i.e., both alter their bid function based on their intended bid rank within the pair). While there is evidence indicating that in 11 of the 13 pairs identified by the across-firm analysis at least one company had suspicious changes in is bid function, only 8 consist of a pair of such companies. This analysis

highlights that despite the conservative approach we've applied to analyzing across-firm suspicious behavior results, there may be companies misidentified as possible colluders by the Bajari and Ye tests. However, the majority of firms identified as plausible conspirators (62%) through the Bajari and Ye tests remain suspect of bid-rigging, even with this additional test.

Table 8
Suspicious Bidding Behavior Across Firms and Internally

Contractor Pairs	Number of Auction Interations
(1)	(2)
(00000008, 00000089)	332
(00000089, 00105709)	84
(00000089, 00149783)	59
(00267073, 00743775)	49
(00267073, 00747612)	112
(00753630, 00754230)	42
(00753630, 00769989)	45

A notable result of this study is the identification of contractors 00000008 and 00000089 (Granite Construction and Teichert Construction) as possible colluders in Table 8. Referring back to Table 3 through Table 5, these two firms won every fifth construction project and accounted for just under a quarter of all highway construction expenditure in the state of California. Positive results in every test and the size and scope of these two contractors' work make them interesting subjects for further investigation. However, as stated earlier our analysis alone cannot be used to definitively conclude that there was or was not involvement in bid rigging.

VII. Methodology Limitations and Future Developments

There are several reasons to take seriously the possibility of measurement error in the analysis. As mentioned earlier the engineering estimate is influenced by the winning bids of past auctions. If a bid-rigging conspiracy occurred and caused an increase in engineering estimates, the normalized bids would be lowered. That would result in a downward bias of the normalized bids. This should mask the effects of the collusion, and hinder detection.

Another aspect which could affect the results is the project distance and capacity calculations. The project distance is measured from the project location to the location submitted by the contractor with its bid. However, some contractors have multiple locations including headquarters, quarries, cement plants, etc. Since not all such locations are revealed in the data, it is possible that the contractor for which project distance is calculated may have

a location closer to the construction site. That would cause us to overestimate the project distance effectively introducing an upward bias in the estimation of that effect. Additionally, a contractor may be involved in other work beside Caltrans highway construction.[12] Since our data access is limited to Caltrans procurement data, capacity has been computed using this data. It is not immediately clear how that would bias the variable calculation, but it is reasonable to assume that the capacity variable is measured with error.

In addition to measurement error, the methodology we use to test for suspicious behavior, both across and within firms, is susceptible to omitted variable bias. The adjusted R-square is between 0.70 and 0.80 for all regressions which suggests the explanatory variables manage to account for most of the variation in normalized bids. However, the remaining 20-30% of the variation which is unexplained may be accounted for through the addition of more explanatory variables related to construction costs.

This analysis provides evidence supporting that there may have been collusion between some Caltrans auction participants. However, the current specification does not address whether any collusion giving rise to the results was over the entire period or a subperiod (i.e., whether or when it may have begun or ended during the period of the data analyzed).

We have not utilized the bid model to estimate damages from any cartel suggested by the analysis. Such an analysis would likely need to consider that impact could extend beyond the projects won by the cartel. That is because, but for the collusion, cartel members' lower bids might have led to them winning additional auctions (with lower Caltrans procurement costs than the actual winners). The issue along with those described above present an opportunity for further research.

VIII. Conclusion

Highway construction constitutes a substantial public expense and use of resources. Successful bid rigging highway construction procurement auctions could lead to the diversion of public resources from other priorities and the misallocation of resources. Thus, detecting and taking measures to prevent bid rigging is critical. This study suggests an expansion of established techniques for screening against antitrust conduct. We apply the developed methodology to the Caltrans procurement auctions held between 2000 and 2016.

[12] Granite Construction which is one of the largest highway procurement contractors is also involved in civil and energy project construction. Most recently Granite has been involved in the controversial interior construction of the Bloomberg offices in New York City.
https://www.nytimes.com/2018/02/26/nyregion/bloomberg-interior-construction-fraud.html

We find statistical evidence suggesting that Granite Construction and Teichert may not have placed bids independently from one another, and their response to common auction factors differed from the response of other participating bidders. These firms also reacted to explanatory factors differently depending on whether their bids were the highest among a pair of plausible conspirators or not. This is consistent with the suspicion that these two companies coordinated on their bids and could have engaged in bid rigging.

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Appendix A

Table 9
Suspicious Bidding Behavior Across Companies

Contractor Pairs	Number of Auction Interations	Conditional Independence Test P-value	Exchangability Test P-value	Combined Test P-value
(1)	(2)	(3)	(4)	(5)
(00000008, 00000089)	***332***	***0.000***	***0.000***	***0.000***
(00000008, 00091712)	*87*	*0.678*	*0.031*	*0.688*
(00000008, 00171432)	29	0.730	0.131	0.766
(00000008, 00211337)	***164***	***0.000***	***0.000***	***0.000***
(00000008, 00238650)	***59***	***0.021***	***0.040***	***0.060***
(00000008, 00282929)	*58*	*0.806*	*0.031*	*0.812*
(00000008, 00388077)	47	0.902	0.617	0.962
(00000008, 00471473)	***73***	***0.019***	***0.008***	***0.027***
(00000008, 00579845)	39	0.572	0.482	0.778
(00000008, 00591940)	59	0.855	0.827	0.975
(00000008, 00592597)	29	0.705	0.884	0.966
(00000008, 00593393)	***62***	***0.004***	***0.041***	***0.045***
(00000008, 00644515)	38	0.726	0.541	0.874
(00000008, 00704195)	102	0.505	0.187	0.597
(00000008, 00709237)	74	0.470	0.062	0.503
(00000008, 00726454)	108	0.423	0.724	0.841
(00000008, 00759729)	**41**	**0.006**	**0.517**	**0.519**
(00000008, 00767055)	32	0.315	0.330	0.541
(00000008, 00772589)	38	0.501	0.142	0.572
(00000008, 00897282)	27	0.898	0.714	0.971
(00000022, 00000089)	**173**	**0.000**	**0.598**	**0.598**
(00000022, 00201696)	*75*	*0.074*	*0.000*	*0.074*
(00000022, 00591940)	**56**	**0.018**	**0.257**	**0.270**
(00000022, 00592597)	33	0.661	0.492	0.828
(00000022, 00704195)	53	0.325	0.919	0.945
(00000022, 00759729)	**54**	**0.029**	**0.780**	**0.786**
(00000022, 00897282)	7	0.822	0.870	0.977
(00000088, 00000089)	109	0.190	0.245	0.389
(00000088, 00116307)	37	0.835	0.429	0.906
(00000088, 00897282)	4	0.370	0.911	0.944
(00000089, 00091712)	*145*	*0.270*	*0.001*	*0.271*
(00000089, 00105709)	***84***	***0.004***	***0.000***	***0.004***
(00000089, 00116307)	73	0.360	0.706	0.812
(00000089, 00132128)	**58**	**0.004**	**0.163**	**0.166**
(00000089, 00140069)	121	0.892	0.686	0.966
(00000089, 00149783)	***59***	***0.013***	***0.006***	***0.019***
(00000089, 00171432)	85	0.154	0.844	0.868
(00000089, 00201696)	***65***	***0.001***	***0.000***	***0.001***
(00000089, 00211337)	*176*	*0.233*	*0.024*	*0.251*

Note: Rows in bold indicate failing the Conditional Independence test, and rows in italic indicate failing the Exchangeability test.

Table 9
Suspicious Bidding Behavior Across Companies

Contractor Pairs	Number of Auction Interations	Conditional Independence Test P-value	Exchangability Test P-value	Combined Test P-value
(1)	(2)	(3)	(4)	(5)
(00000089, 00238650)	84	0.095	0.249	0.320
(00000089, 00264193)	57	0.977	0.249	0.983
(00000089, 00267073)	38	0.261	0.144	0.367
(00000089, 00282929)	**141**	**0.000**	**0.080**	**0.080**
(00000089, 00295418)	*43*	*0.167*	*0.032*	*0.193*
(00000089, 00357560)	44	0.114	0.909	0.919
(00000089, 00388077)	51	0.274	0.683	0.770
(00000089, 00414567)	59	0.294	0.510	0.654
(00000089, 00471473)	**194**	**0.027**	**0.087**	**0.112**
(00000089, 00523019)	**115**	**0.001**	**0.203**	**0.203**
(00000089, 00579845)	49	0.129	0.531	0.592
(00000089, 00591940)	104	0.377	0.350	0.595
(00000089, 00592597)	61	0.180	0.765	0.807
(00000089, 00593393)	123	0.139	0.365	0.453
(00000089, 00644515)	**81**	**0.008**	**0.420**	**0.425**
(00000089, 00676166)	**77**	**0.000**	**0.338**	**0.339**
(00000089, 00684075)	60	0.393	0.372	0.619
(00000089, 00704195)	**136**	**0.044**	**0.948**	**0.950**
(00000089, 00709237)	88	0.649	0.115	0.689
(00000089, 00726454)	**127**	**0.006**	**0.176**	**0.182**
(00000089, 00747612)	**92**	**0.007**	**0.781**	**0.783**
(00000089, 00750542)	74	0.101	0.732	0.760
(00000089, 00753630)	*61*	*0.057*	*0.000*	*0.057*
(00000089, 00754230)	**69**	**0.020**	**0.142**	**0.160**
(00000089, 00759729)	87	0.989	0.900	0.999
(00000089, 00767055)	**100**	**0.022**	**0.496**	**0.507**
(00000089, 00769989)	*49*	*0.084*	*0.000*	*0.084*
(00000089, 00772589)	55	0.420	0.770	0.867
(00000089, 00776848)	53	0.151	0.128	0.260
(00000089, 00897282)	60	0.284	0.966	0.976
(00091712, 00211337)	***39***	***0.022***	***0.001***	***0.023***
(00091712, 00295418)	55	0.060	0.501	0.531
(00091712, 00593393)	54	0.376	0.489	0.681
(00091712, 00704195)	44	0.448	0.094	0.500
(00091712, 00726454)	50	0.988	0.403	0.993
(00091712, 00753630)	*45*	*0.130*	*0.020*	*0.148*
(00091712, 00754230)	*45*	*0.721*	*0.027*	*0.728*
(00091712, 00769989)	40	0.087	0.486	0.531
(00105709, 00769989)	**52**	**0.007**	**0.587**	**0.590**
(00116307, 00267073)	**43**	**0.001**	**0.180**	**0.180**
(00116307, 00747612)	57	0.995	0.827	0.999

Note: Rows in bold indicate failing the Conditional Independence test, and rows in italic indicate failing the Exchangeability test.

Table 9
Suspicious Bidding Behavior Across Companies

Contractor Pairs	Number of Auction Interations	Conditional Independence Test P-value	Exchangability Test P-value	Combined Test P-value
(1)	(2)	(3)	(4)	(5)
(00116307, 00897282)	5	0.378	0.941	0.963
(00132128, 00171432)	**64**	**0.025**	**0.252**	**0.271**
(00132128, 00238650)	**66**	**0.036**	**0.678**	**0.690**
(00132128, 00357560)	49	0.091	0.934	0.940
(00132128, 00644515)	**110**	**0.040**	**0.474**	**0.495**
(00132128, 00759729)	82	0.887	0.753	0.972
(00140069, 00149783)	*50*	*0.801*	*0.009*	*0.803*
(00140069, 00414567)	38	0.278	0.702	0.785
(00140069, 00747612)	**43**	**0.027**	**0.796**	**0.802**
(00149783, 00414567)	*47*	*0.194*	*0.034*	*0.221*
(00171432, 00357560)	67	0.654	0.925	0.974
(00171432, 00644515)	78	0.051	0.377	0.409
(00171432, 00676166)	**43**	**0.024**	**0.505**	**0.517**
(00171432, 00709237)	42	0.836	0.711	0.953
(00211337, 00388077)	**48**	**0.038**	**0.683**	**0.695**
(00211337, 00592597)	18	0.558	0.332	0.704
(00211337, 00593393)	34	0.288	0.372	0.553
(00211337, 00704195)	46	0.603	0.218	0.690
(00211337, 00709237)	41	0.343	0.165	0.451
(00211337, 00726454)	***68***	***0.000***	***0.009***	***0.009***
(00211337, 00776848)	*24*	*0.588*	*0.027*	*0.599*
(00211337, 00897282)	14	0.577	0.581	0.823
(00238650, 00591940)	57	0.074	0.531	0.565
(00238650, 00592597)	34	0.503	0.578	0.791
(00238650, 00644515)	67	0.054	0.521	0.547
(00238650, 00704195)	72	0.237	0.766	0.821
(00238650, 00759729)	89	0.436	0.729	0.847
(00264193, 00523019)	48	0.152	0.382	0.476
(00267073, 00688659)	*109*	*0.071*	*0.034*	*0.103*
(00267073, 00743775)	***49***	***0.031***	***0.019***	***0.049***
(00267073, 00747612)	***112***	***0.001***	***0.043***	***0.044***
(00267073, 00782908)	78	0.200	0.849	0.880
(00282929, 00471473)	*108*	*0.354*	*0.044*	*0.382*
(00282929, 00767055)	32	0.877	0.550	0.945
(00282929, 00772589)	22	0.322	0.509	0.667
(00282929, 00897282)	17	0.531	0.963	0.983
(00295418, 00593393)	14	0.627	0.209	0.705
(00295418, 00753630)	49	0.295	0.129	0.386
(00295418, 00754230)	*38*	*0.522*	*0.006*	*0.524*
(00295418, 00769989)	**82**	**0.006**	**0.123**	**0.128**
(00357560, 00644515)	56	0.118	0.837	0.856

Note: Rows in bold indicate failing the Conditional Independence test, and rows in italic indicate failing the Exchangeability test.

Table 9
Suspicious Bidding Behavior Across Companies

Contractor Pairs	Number of Auction Interations	Conditional Independence Test P-value	Exchangability Test P-value	Combined Test P-value
(1)	(2)	(3)	(4)	(5)
(00357560, 00676166)	**36**	**0.007**	**0.648**	**0.650**
(00388077, 00897282)	12	0.907	0.956	0.996
(00414567, 00747612)	**31**	**0.031**	**0.314**	**0.335**
(00471473, 00767055)	26	0.203	0.250	0.402
(00471473, 00772589)	25	0.968	0.260	0.976
(00471473, 00897282)	23	0.446	0.408	0.672
(00523019, 00767055)	**44**	**0.002**	**0.233**	**0.234**
(00579845, 00767055)	**25**	**0.034**	**0.745**	**0.754**
(00591940, 00592597)	28	0.297	0.920	0.943
(00591940, 00704195)	70	0.897	0.708	0.970
(00591940, 00759729)	**63**	**0.048**	**0.890**	**0.895**
(00592597, 00644515)	23	0.612	0.717	0.890
(00592597, 00704195)	39	0.394	0.840	0.903
(00592597, 00759729)	30	0.134	0.915	0.926
(00592597, 00772589)	10	0.840	0.597	0.935
(00593393, 00684075)	**35**	**0.041**	**0.925**	**0.928**
(00593393, 00754230)	27	0.696	0.332	0.797
(00644515, 00704195)	51	0.439	0.768	0.870
(00644515, 00709237)	47	0.363	0.089	0.420
(00644515, 00759729)	92	0.472	0.775	0.881
(00676166, 00726454)	34	0.990	0.306	0.993
(00676166, 00897282)	4	0.431	0.932	0.961
(00688659, 00743775)	**37**	**0.000**	**0.173**	**0.173**
(00688659, 00747612)	88	0.820	0.107	0.839
(00688659, 00782908)	**47**	**0.047**	**0.261**	**0.296**
(00704195, 00759729)	**80**	**0.002**	**0.958**	**0.958**
(00704195, 00772589)	16	0.919	0.770	0.981
(00709237, 00726454)	67	0.173	0.252	0.381
(00709237, 00753630)	*24*	*0.376*	*0.038*	*0.399*
(00753630, 00754230)	***42***	***0.003***	***0.000***	***0.003***
(00753630, 00769989)	***45***	***0.009***	***0.019***	***0.028***
(00754230, 00769989)	*49*	*0.113*	*0.001*	*0.115*
(00772589, 00897282)	13	0.432	0.866	0.924

Note: Rows in bold indicate failing the Conditional Independence test, and rows in italic indicate failing the Exchangeability test.

Table 10
List of Company Pairs that Failed
Conditional Independence and Exchangeability Tests

Contractor Pairs	Number of Auction Interations
(1)	(2)
(00000008, 00000089)	332
(00000008, 00211337)	164
(00267073, 00747612)	112
(00000089, 00105709)	84
(00000008, 00471473)	73
(00211337, 00726454)	68
(00000089, 00201696)	65
(00000008, 00593393)	62
(00000089, 00149783)	59
(00267073, 00743775)	49
(00753630, 00769989)	45
(00753630, 00754230)	42
(00091712, 00211337)	39

Table 11
Internal Bidding Behavior Consistency
For Firms in Pairs with Suspicious Bidding

Contractor Pairs	P-value for Internal Bidding Consistency of Company A	P-value for Internal Bidding Consistency of Company B	P-value for Internal Bidding Consistency of Both Companies
(1)	(2)	(3)	(4)
(00000008, 00000089)	0.0000 ***	0.0000 ***	0.0000 ***
(00000008, 00211337)	0.0611 *	0.0000 ***	0.0611 *
(00000008, 00471473)	0.0304 **	0.4812	0.4970
(00000008, 00593393)	0.4834	0.0594 *	0.5141
(00000089, 00105709)	0.0004 ***	0.0005 ***	0.0009 ***
(00000089, 00149783)	0.0056 ***	0.0137 **	0.0193 **
(00000089, 00201696)	0.1293	0.0004 ***	0.1297
(00091712, 00211337)	0.5590	0.5233	0.7898
(00211337, 00726454)	0.0000 ***	0.5044	0.5044
(00267073, 00743775)	0.0048 ***	0.0046 ***	0.0094 ***
(00267073, 00747612)	0.0000 ***	0.0089 ***	0.0089 ***
(00753630, 00754230)	0.0063 ***	0.0000 ***	0.0063 ***
(00753630, 00769989)	0.0003 ***	0.0121 **	0.0123 **