Administrative Council for Economic Defense
Departament of Economic Studies

Working Paper

Nº 005/2019

Using the Moran's I to Detect Bid Rigging in Brazilian Procurement Auctions

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Brasília, December 2019

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Administrative Council for Economic Defense

Ministry of Justice and Public Security

Administrative Council for Economic Defense

Using the Moran's I to Detect Bid Rigging in Brazilian Procurement Auctions[1]

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[1] Esse trabalho foi realizado por meio de uma cooperação técnico-científica envolvendo o Departamento de Estudos Econômicos do CADE e a Secretaria de Perícia, Pesquisa e Análise do MPF. Além disso, o trabalho decorre de um projeto de pesquisa financiado com recursos da Escola Superior do Ministério Público da União (ESMPU) através do Edital 01129/2017. O projeto de pesquisa contou com a participação de José Jorge Gabriel Júnior (SPPEA/MPF), Ricardo Carvalho de Andrade Lima (SPPEA/MPF), Vitor Januário Oliveira (SPPEA/MPF) e Guilherme Mendes Resende (DEE/CADE).

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Executive Summary

In 2015, a supposed bid-rigging cartel that operated in the Brazilian implantable cardiac devices market was announced and public authorities began to investigate it. This paper evaluates if there is systematic correlation between the bids that are placed by competitors in the sealed phase of procurement auctions, which is a situation that may suggest coordinated and fraudulent behaviour. By applying Moran's I statistic to the residuals of controlled bid regressions and using a novel and public database, we show that the bids that were placed by the investigated companies have positive and statistically significant autocorrelation. In addition, when we separate the data into two subperiods, namely, the period in which the cartel probably existed (2005-2015) and the period in which the cartel probably did not exist due to the conclusion of a leniency agreement (2015-2017), the Moran's I statistic only points to autocorrelation in the first sub-sample. Our result has remained robust when we eliminate transitional periods and use alternative economic screens.

The main advantage of the economic screen based on Moran's I statistic is its low data requirements and computational and statistical simplicity. In addition, the screen is versatile and can be applied to any type of market where public procurement occurs using sealed auctions. However, Moran's I statistic requires prior knowledge of the identity of the companies that may form the bid-rigging cartel. Without information from documentary evidence, denunciations or leniency agreements, it becomes more difficult to construct the bidding matrix and to apply the screen. A partial solution to this disadvantage is to apply the economic screen to combinations of all sets of companies or apply it only to those with the largest market shares or to the most frequent bidders. Finally, another shortcoming of our economic screen is the possibility of finding the existence of a bid-rigging cartel when one does not truly exist (false positives). This can occur when bids are correlated due to the existence of unobserved variables that influence the placed bids. Therefore, our screen cannot be used as isolated and definitive proof of the existence of a bid-rigging scheme and it is necessary to collect additional documentary evidence.

Keywords: Bid-Rigging, Spatial Econometrics, Procurement Auctions, Cartel and Collusion.

Summary

1. Introduction

Bid-rigging occurs when a group of companies participating in a public procurement establish cooperative agreements with each other to raise prices, divide the market or reduce the quality of goods and services that are purchased by the public administration. Considering that public procurement accounts for an estimated 15% of gross domestic product (GDP) worldwide on average, according to the Organisation for Economic Co-operation and Development (2009), and the cartel overcharges by approximately 16% (Boyer and Kotchoni, 2015), bid-rigging schemes can roughly result in economic losses of approximately 2.3% of GDP in the public sector budget. In addition to the reduction in economic welfare resulting from the transfer of resources from society to cartel members, the practice also causes intangible damage to the economy. For example, cartelization tends to inhibit the entry of new, potentially more efficient competitors and, in addition, reduce incentives for innovations (as measured by investments in R&D), as evidenced by Günster et al. (2011).

For these reasons, the detection of and fight against bid-rigging cartels has become a priority of antitrust authorities and anti-corruption agencies around the world. Relative to detection, public authorities may act in a reactive or proactive way. In the first case, the investigation is opened when an anonymous complaint occurs or when a cartel member makes a delation, which is a situation that materializes in leniency programmes. Although it is an efficient strategy, leniency agreements have the limitation of detecting only those cartels that are unstable and are close to breaking points such that successful cartels remain unscathed (Abrantes-Metz and Bajari, 2012). Therefore, it is essential to use a proactive approach in such a way that public authorities are no longer dependent on external information to initiate a cartel investigation. An example of a proactive practice is the use of economic screens. Economic screens are characterized as statistical tests that seek to identify anomalous patterns in the distribution of economic variables (prices, costs, proposals, bids and market shares) that resemble non-competitive behaviour[2]. In the present paper, we use an economic screen that identifies the systematic correlation between bids to investigate the

[2] As emphasized by Harrington (2008), the objective of economic screens is to identify the markets with high probabilities of collusion. Thus, the screens do not definitively prove the existence of a cartel and, like any other statistical test, may result in false positives or false negatives. Therefore, economic screens function as a step to determine in which markets it is necessary to open an investigative process or to conduct searches and seizures.

behaviour of a bid-rigging cartel. More specifically, we follow the methodology that was recently proposed by Lundberg (2017) in which Moran's I statistic is applied to the residuals of a bid regression to detect complementary bidding on public contracts. The proposed screen is applied to a supposed bid-rigging cartel that operates in the implantable cardiac device (ICD) market in Brazil. This bid-rigging scheme is being investigated by the Administrative Council for Economic Defense (CADE) and includes a partial leniency agreement involving a company that participates in the alleged collusion. The market covers the sector of implantable cardiac devices, which includes resynchronizers, pacemakers and accessory items such as electrodes and catheters. According to the investigative process, the cartel operated between 2004 and 2015 in all Brazilian territories and comprised a group of four companies, twenty-nine individuals and two industrial associations.

There is a vast empirical related literature that implements different types of economic screens to detect cartel behaviour in public procurement. One tool that is traditionally employed is the variance screen. It is expected that the variance of the bids' distributions will be lower in the presence of bid-rigging cartels. According to Imhof (2017), the idea is that by establishing collusion, cartel members exchange information and coordinate their bids to reach a minimum contract value, which tends to be higher than the contract value in the case of competition. This practice restricts the possible universe of bid values (truncates the distribution) and, consequently, reduces the variance. Abrantes-Metz et al. (2006) have shown that after the collapse of a bid-rigging cartel that supplied seafood to Philadelphia's military installations in the 1980s, the average price of the products decreased by 26% and the standard deviation increased by over 260%. The studies of Imhof (2017) and Imhof et al. (2018) that investigated bid-rigging cartels that operated in the road construction sector in Switzerland also apply the variance screen as one of the stages of cartel detection, claiming that this statistic is easy to implement due to the few data requirements and the low level of complexity in its calculation.

In sealed-bid procurement auctions, companies submit their bids simultaneously so that bid values are only revealed at the end of the auction and on a specific date. Commonly, the public administration establishes the company that gives the lowest bid value as the winner of the auction. In this way, if there is no coordination between the firms, individual bids will not be conditioned on competitors' bids. Therefore, it is expected that the bids will

be independent of each other after the control of the observed information. This condition - known as the conditional independence hypothesis - was initially established by Bajari and Ye (2003) to characterize a distribution of bids that are to be generated by a model with competitive bidding. A set of empirical studies sought to detect bid-rigging cartels by analysing the interdependence between the bids. Jakobsson (2007) tested the validity of the conditional independence hypothesis for asphalt-paving procurement auctions in Sweden by applying the spearman rank correlation to pairs of bids. Aryal and Gabrielli (2013) developed a two-step procedure using the Bajari and Ye (2003) approach and a structural model was applied to asymmetric first-price auctions that compares bidder costs in both collusion and non-collusion scenarios. More recently, the conditional independence was analysed using spatial statistical tools, allowing the hypothesis to be tested in a more flexible way by not limiting the tests to pairs of bidders. Bergman et al. (2019) used spatial econometric models and Lundberg (2017) applied Moran's I statistic to detect whether there is systematic correlation between the bids of a group of companies that were accused of operating an asphalt bid-rigging cartel in Sweden from 1995 to 2001.

In addition to a smaller variance and interdependent bids, another common characteristic of bid-rigging cartels is the rotation of winners. The rotating behaviour of a cartel consists of the artificial exchange of the winning bidder in procurement auctions that are frequently conducted by public administrations. The study of Ishii (2009) analysed this behaviour in a detailed way. Using data from the public procurement auctions of Naha city (Japan) for consulting services, Ishii (2009) showed that the variable that measures the favour exchange score of a particular company in repeated auctions positively affects the win probability at a future auction. This evidence suggests that there was a bid-rigging cartel operating based on favour exchange with a rotational scheme. Imhof (2017) and Imhof et al. (2018) also proposed a graphical analysis of the bids that allows one to check the existence of rotating behaviour in pairs of competing companies.

Considering this empirical literature on economic screens being applied to bid-rigging cartels, we intend to contribute in two ways, i.e., I) by applying a methodology that allows one to test the conditional independence hypothesis in a more flexible manner in relation to previous studies and II) by analysing the behaviour of an investigated bid-rigging cartel that operated in the Brazilian market for implantable cardiac devices using a novel and public

database. It should be noted that, to our best knowledge, there are not any empirical studies that employed economic screenings to investigate bid-rigging in Brazilian procurement auctions. Most of the screens have been applied to detect price-fixing cartels operating in the fuel station sector (see, for example, Ragazzo and Silva 2006; Vasconcelos and Vasconcelos, 2005).

The remainder of the paper is organized as follows. Section 2 presents a brief description of the supposed bid-rigging cartel that operated in the ICD market and describes the main rules of Brazilian procurement auctions. In section 3, we present the econometric setup of the study, and, in section 4, we describe the database and descriptive statistics. In section 5, we show and discuss the results. Finally, in section 6, we present the conclusions of the paper and summarize the main practical advantages and disadvantages of applying our screen.

2. Institutional Background

2.1. Description of the supposed bid-rigging cartel

To evaluate the suitability of the screen based on Moran's I statistic, we will analyse a supposed bid-rigging scheme that operated in the Brazilian market for implantable cardiac devices[3] (ICD). The disclosure of the alleged bid-rigging cartel began in January 2015 when the Ministry of Health - the public agency that purchases medicines, medical prostheses and hospital equipment for the provision of public health services – made a set of complaints pointing to fraud involving ICD suppliers. Initially, there were indications that ICD procurement auctions were being defrauded based on observations of the following practices: identical allocation of contracts, bidding only for contracts that would be effectively won, and the existence of figurative or coverage bids. After the complaint, the Administrative Council for Economic Defense (CADE) and the Federal Prosecutor's Office (MPF) began investigating the case and, in addition, two Parliamentary Inquiry Committees were opened.

In November 2015, an involved company signed a partial leniency agreement with CADE confessing to the bid-rigging scheme in the ICD market and committing to cooperate with the investigations. Due to the collaboration, the company obtained reduced administrative and criminal penalties. After the conclusion of the leniency agreement, the competition authority conducted search and seizure operations at the headquarters and offices of the involved companies and gathered more robust evidence about the existence of the bid-rigging cartel. Among the collected evidence is a document that was created by the set of companies that contains a schedule that outlines the firms that would win future ICD procurement auctions (Abreu 2018). According to the administrative process, the bid-rigging scheme operated in Brazil from 2004 to 2015 and was operated by the four largest companies in the ICD market (CADE 2017) [4]. The scheme was coordinated through face-to-face meetings involving company directors and, in some situations, was intermediated by industry associations. Public managers and physicians also participated in the bid-rigging scheme by facilitating the defrauding of

[3] The implantable cardiac device market involves the following items: (I) implantable dual-chamber and unicameral defibrillator cardioverters; (II) cardiac resynchronizers; and (III) pacemakers and accessories, which include (IV) temporary and definitive endocardial electrodes, (V) sets of introducers and (VI) catheters.

[4] More information available at: http://www.cade.gov.br/noticias/superintendencia-instaura-processos-para-apurar-cartel-no-mercado-de-orteses-proteses-e-materiais-medicos-especiais .

public procurement auctions and simulating the need for ICDs in exchange of bribes that were provided by the companies.

The anticompetitive practices that were investigated are the following: the exchange of price information, supply agreements, customer allocations between competitors and combinations of proposals in the sealed bidding phase. Currently, the case is still being evaluated by the technical area of CADE and the investigation involves four companies, 29 individuals and two industrial associations.

2.2. Procurement auction procedures in the ICD market

The public procurement auctions that were created for the purchase of ICD items are mostly carried out electronically[5] and are governed by the rules of Brazilian Enactment 5.450/2005. In the electronic modality, the public procurement auctions take place virtually and have two different stages. In the first stage, each of the competitors makes their bid by delivering a sealed envelope with the bid value to the auction organizer, and it functions as a sealed-bid auction. Following the opening of the envelopes, the second stage of the acquisition process starts with a downward oral auction (with simultaneous bids) starting with the bid values that were made by the bidders in the first stage. It is not possible for a competitor to bid higher than their last registered bid. The auction winner is the company that makes the lowest bid in the second phase. Another important feature of the electronic modality is that there is complete anonymity of bidders' identities both in the first stage and in the second stage. According to Mattos (2014), this characteristic introduces a destabilizing element for cartel formation since it becomes more difficult to discover possible deviations from the collusive agreements.

Taking these rules into consideration, coordinating first-stage bids makes it possible to establish a larger starting point for the second stage and avoids offering low-value bids. This potentially favours a higher contract price than that in the case of competition and facilitates the direction of the acquisition process. In this way, our screening method seeks to capture possible bid coordination in the first stage of an electronic procurement auction, which would be an indication of a broader collusive agreement.

[5] Only 18 of the 1351 ICD contracts that we analyzed were from live auctions.

3. Methodology

Before calculating Moran's I statistic, it is necessary to construct a weighting matrix (also called a bidding matrix) that associates the set of potentially cartelized firms with each other. The bidding matrix was applied by Lundberg (2017) and Bergman et al. (2019) and is constructed similarly to traditional spatial matrices that are used to establish geographical relations between different spatial units. Initially, it is assumed that there are two types of bidders: those that engage in collusive activities (type A firms) and those that act competitively (type B firms). In first-price sealed auctions, type A firms place complementary bids while the bids that are placed by type B firms and across type A and type B firms tend to be independent. The complementarity of bids is a strategy that simulates competition and is commonly adopted by bid-rigging cartels. It is when a firm (as previously defined by cartel members) bids lower to win the procurement auction while other cartel members offer higher bids in exchange for future rewards, such as subcontracting, consortium formation, or winning other auctions, for example. In the context of the Brazilian ICD procurement auctions, complementary bidding in the first stage of an electronic auction can be an optimal strategy to manipulate the final auction outcome (see subsection 2.2) and allows for potential overcharges in contracts.

We denote b_{ic} as the bid value that is placed by firm i on contract c, n_a is the number of bids that is placed by type A companies, n_b is the number of bids that is placed by type B companies and n_c is the total number of bids, which is equal to the total number of observations as $N = n_c = n_a + n_b$. We define the bidding matrix as a matrix $\boldsymbol{W}$ of dimension NxN with elements $w_{ic,jc}$ such that $w_{ic,jc} > 0$ if $i \neq j$ and $i, j \in A$. Otherwise, $w_{ic,jc} = 0$. It is observed that the bids are independent across the different contracts ($w_{ic,jk} = 0\ if c \neq k$) and independent between the set of non-collusive bidders ($w_{ic,jc} = 0$ if $i \in B$ or/and $j \in B$). Finally, the magnitude of matrix $\boldsymbol{W}$**'s** weights is defined as follows: $w_{ic,jc} = 1/(N_{AC} - 1)$, where N_{Ac} is the number of type A firms participating in the procurement auction for contract c. This adjustment allows us to obtain a row standardized matrix. There are situations in which the identity of the companies participating in bid-rigging schemes (type A firms) is unknown. In this case, Lundberg (2017) suggests defining potential cartel members on the basis of some prior suspicion (obtained through denunciations or leniency programmes, for example) or by

constructing a set of bidding matrices that simulate possible cartel combinations between three or four companies with higher market power or those that participate in the procurement auctions more frequently.

To detect complementary bidding behaviour - which may indicate the existence of a bid-rigging scheme - the next step is to calculate the global Moran's I statistic, which was developed by Moran (1948) and has been widely used to detect the existence of spatial autocorrelation. The global Moran's I statistic is obtained by calculating the following expression:

$$I = \frac{\sum_i \sum_j w_{ic,jc} \, (b_{ic} - \mu)\big(b_{jc} - \mu\big)}{\sum_i (b_{ic} - \mu)^2} \qquad (1)$$

Here, $w_{ic,jc}$ is the elements of bidding matrix $\boldsymbol{W}$ that is described above, b_{ic} is the bid value that is placed by firm i on contract c, b_{jc} is the bid value that is placed by firm j and, finally, μ is the average bid value. Under the hypothesis of the absence of autocorrelation, it is possible to demonstrate that the expectation of Moran's I statistic is given by $E(I) = -1/(N-1)$, and it tends to zero to the extent that $N \to \infty$. To detect if there is autocorrelation between the bids, the null hypothesis $H_0: I = -1/(N-1)$ and the alternative hypothesis $H_a: I \neq -1/(N-1)$ are tested. If the null hypothesis is rejected, Moran's I test indicates the existence of autocorrelation between the bids. In this case, there is evidence that companies are adopting complementarity bidding behaviour in a systematic way, which is characteristic of bid-rigging arrangements. The value of Moran's I statistic ranges from -1 to +1. Negative values indicate negative autocorrelation and positive values indicate positive autocorrelation.

The problem with this approach is that bids may be autocorrelated in sealed auctions due to natural market factors that are not necessarily related to collusive behaviour. For example, bids tend to be correlated when the different companies participating in the procurement auction have similar cost structures, operate in the same geographic market, or have similar scales of production or when the bidding process is related to the supply of goods and services in a specific area. In these situations, Moran's I test can generate a series of false

positives. One way to minimize this problem is to estimate a bid regression to generate b_{ic} free from the influence of market variables. In this sense, we apply Moran's I statistic to the residuals of the following bid regression:

$$b_{ic} = \gamma X_{ic} + \theta_s + \lambda_p + \mu_i + \varepsilon_{ic} \qquad (2)$$

Here, b_{ic} is the dependent variable and X_{ic} is set of controls that capture the observable variables (company-specific and contract-specific) that have the potential to influence the magnitude of the placed bids. In addition to the observable variables, the bid regression can be estimated by including the unobserved fixed-effects that are associated with the type and specification of the ICD item in question (θ_s), procurement specific effects (λ_p), and firm specific effects (μ_i). Therefore, when applying Moran's I statistic to the residuals of equation (2), a potential systematic correlation between the bids can be attributed to other unobservable variables, which include the collusive behaviour.

4. Data and Descriptive Statistics

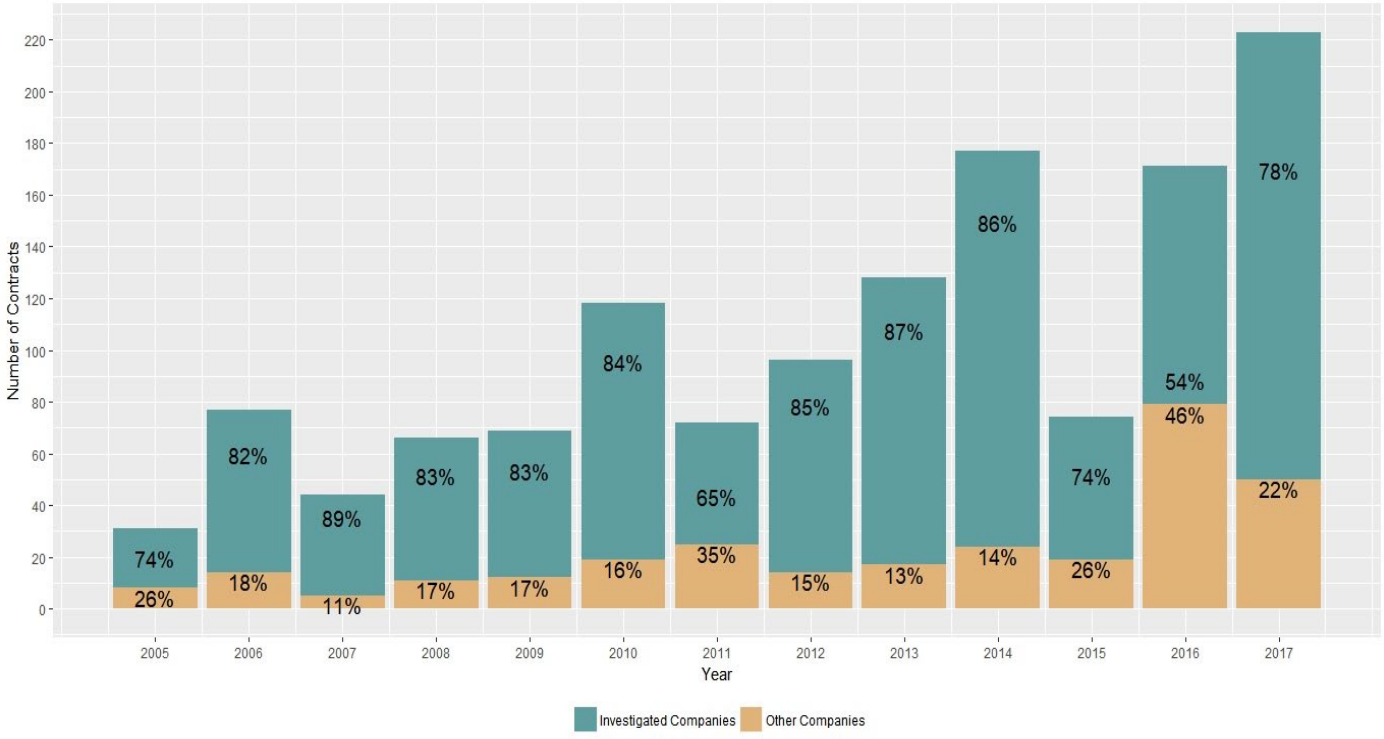
The database that is used in the present study is public and was obtained from the Integrated Administration and General Services System (Comprasnet - SIASG) of the Brazilian Federal Government. In this platform, the public administration operates and retains the information regarding its purchases and contracts. This includes the registration and disclosure of public procurements, the corresponding records of prices and the suppliers' identities and the registration and management of contracts. Considering our objective, we filtered this database to get the information from the procurement auctions of the implantable cardiac devices (ICD) market involving the participation of at least one of the firms that has been investigated for bid-rigging collusion.

Thus, we obtained a dataset containing information on 238 public procurements involving 1351 different contracts[6] and 4679 bids that were submitted by 147 companies in

[6] A single public procurement may involve several different contracts. Thus, competition occurs at the contract level.

the period from January 2005 to December 2017. The following information is available in our database: the date of public procurement, the identities of bidders, the auction modality (electronic or live mode), the municipality and public agency that were responsible for the purchase, the product code[7], the product specification, the bid values that were placed in the first stage of the auction, the estimated value[8] provided by the public administration, the number of demanded items, the identification of the winner and the final value of the purchased item. Figure 1 shows the evolution of the total number of ICD contracts per year and the respective proportion of contracts that was won by the four companies that were investigated for bid-rigging collusion.

Figure 1 - Evolution of the Number of Contracts in the ICD market



Note: Own elaboration based on SIASG data.

We note that there is strong variability in the number of contracts that are signed each year and an abrupt drop in 2015 (58% in relation to the previous year), coinciding exactly with the year in which the leniency agreement was concluded with CADE. In addition, it is noted

[7] There are 366 different categories of implantable cardiac devices.

[8] The estimated value of the item or reference value is a cost estimate that the requesting public agency stipulates as a forecast of how much will be spent on the contract.

that the companies that were investigated for bid-rigging have substantial participation in the ICD market with participation varying from 54% to 89% per year.

Regarding the variables that were used in the bid regression estimation, our dependent variable will be the ratio between the bid value that is placed in the first stage of an electronic auction and the corresponding bid value that was estimated by the public administration. This adjustment using the estimated bid value is important to eliminate the effects that are generated by bidding for a common target, which would generate spurious correlation between the placed bids of different competitors. In addition, this is also useful for standardizing the unit of measure of the dependent variable since the monetary values of ICD items tend to vary according to their different types and specifications. In the vector of control variables, we will include the following: I) the Capacity Rate of firm i, which is defined as the ratio between the number of contracts that are won by the firm up to the date of contract c and the total number of contracts that can be obtained until the end of the year in question; II) the number of employees of firm i; III) the number of competitors participating in the procurement auction for contract c, and IV) the number of ICD items to be contracted by the public administration through contract c. The number of employees for each firm was obtained through the Annual Report of Social Information (RAIS) of the Ministry of Labor and Employment (MTE) and the number of competitors, the capacity rate, and the number of items per contract were directly calculated using our bid data. Table 1 shows the mean and standard deviation of the variables for the entire data set, for the subset that is restricted to the period in which the bid-rigging cartel was supposed to operate (January 2005 to October 2015) and for the subset that is restricted to the period following the conclusion of the leniency agreement (November 2015 to December 2017).

Table 1 – Descriptive Statistics: Mean and Standard Deviation

	Whole Sample (2005-2017)	Cartel Period (2005-2015)	Post-Cartel Period (2015-2017)
Relative Bid	1.106	1.082	1.163
	(0.44)	(0.42)	(0.471)
Actual Bid (in R$)	11495.933	11419.424	11675.06
	(16754.09)	(16766.42)	(16729.86)
Estimated Bid Value (in R$)	10922.532	11064.977	10589.028
	(15659.35)	(15757)	(15428.8)
Capacity Rate	0.492	0.482	0.517
	(0.43)	(0.38)	(0.52)
Number of Employees	339.2	314	345.5
	(331.4)	(334.6)	(345.9)
Number of Competitors	3.754	3.835	3.564
	(1.095)	(1.17)	(0.86)
Number of Items	91.798	93.2	88.514
	(174.26)	(177.286)	(166.97)
Number of Procurements	238	202	36
Number of Contracts	1351	928	423
Number of Observations (Bids)	4679	3293	1386

Note: Standard deviation in parentheses. The bid value and estimated bid are in current currency (in Brazilian Reais, R$).

From Table 1, it can be observed that there are no large discrepancies in the descriptive statistics of the variables that were selected between the period of the alleged bid-rigging (2005 to 2015) and the period after the leniency agreement (2015 to 2017). At first, this suggests that there was no structural change in the implantable cardiac device market.

5. Results

5.1. Main Results

Table 2 shows the results of the estimation of equation (2) using the Ordinary Least Squares (OLS) with three different specifications. The first one (column (1)) considers only the inclusion of the observed control variables, the second (column (2)) adds the firm fixed effect and the ICD type fixed effect and the third specification (column (3)) presents the specification adding the procurement fixed effects. The dependent variable is the log of the adjusted bid value.

Table 2 - Bid Regression for ICD public procurements (2005 to 2017)

	(1)	(2)	(3)
Intercept	0.4191***	0.0729	0.7179**
	(0.049)	(0.284)	(0.304)
Capacity Rate	-0.0526***	-0.0478***	-0.0386
	(0.020)	(0.019)	(0.029)
log (Employees)	-0.0730***	-0.0298	-0.0853***
	(0.0063)	(0.0286)	(0.0328)
Number of Competitors	0.0238***	-0.0013	0.0196
	(0.008)	(0.008)	(0.016)
Number of Items	-0.0002***	-0.0002***	-0.0002***
	(0.000)	(0.000)	(0.000)
ICD Specification FE	No	Yes	Yes
Firm FE	No	Yes	Yes
Procurement FE	No	No	Yes
F-Test	52.37***	12.4***	9.769***
Adjusted R^2	0.042	0.369	0.461
Moran's I Statistic	0.266***	0.380***	0.384***
Number of Observations	4679	4679	4679

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors in parenthesis. The Moran's I statistic is calculated using the row-standardized bidding matrix described in section 2. The dependent variable is the log of the adjusted bid value.

The Moran's I statistic that is calculated for the residuals of the bid regressions is shown at the bottom of the Table 2. As seen, independent of the specification, the Moran's I statistic is positive and statistically significant. This evidence indicates that the bids that are placed by the companies that were investigated for bid-rigging in the ICD market have a positive autocorrelation, thereby violating the hypothesis of conditional independence. In practical terms, this positive correlation between the bids of different competitors in the first stage of the electronic auction (which is a sealed auction) can suggest the existence of a coordinated scheme that is characterized by complementary bidding. Thus, our economic screen captures exactly what was identified by the documentary evidence that were collected by the Brazilian competition authority (see subsection 2.1).

Regarding the covariates, we observed a negative association between the capacity rate and the placed bid, indicating that firms that are closer to their supply limit end up making more aggressive bids. However, this counterintuitive relationship does not hold in the most complete specifications (column (3)). The log of the number of employees (which is a *proxy* for firm size) and the number of items that are demanded in each contract also negatively affect the values of the placed bids. This indicates that competitors tend to bid more

aggressively when the firm size is larger and there is a greater possibility of economies of scale, which is an expected result. The number of competitors for a specific contract does not affect the behaviour of companies in ICD procurement auctions.

Table 3 shows the estimates of our bid regression and the Moran's I statistic for two data periods: the period from January 2005 to October 2015 (the period in which there is documented evidence of the operation of a bid-rigging scheme) and the period between November 2015 and December 2017, which is when it is likely that the bid-rigging cartel did not operate due to the conclusion of a leniency agreement with CADE. We show the results of the more complete bid regression specification.

Table 3 – Bid Regression for ICD public procurements using different subsamples.

	Cartel Period (2005-2015)	Post-Cartel Period (2015-2017)
	(1)	(2)
Intercept	1.9081***	-1.8252***
	(0.479)	(0.396)
Capacity Rate	-0.0555	0.0673*
	(0.038)	(0.040)
log (Employees)	-0.3519***	0.5908***
	(0.050)	(0.090)
Number of Competitors	-0.0004	0.0837***
	(0.021)	(0.021)
Number of Items	-0.0004***	-0.0001
	(0.000)	(0.000)
ICD Fixed-Effect	Yes	Yes
Firm Fixed-Effect	Yes	Yes
Procurement FE	Yes	Yes
F-Test	8.567***	11.58***
Adjusted R^2	0.4714	0.4782
Moran's I Statistic	0.4441***	-0.02263
Number of Observations	3293	1386

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors in parenthesis. The Moran's I statistic is calculated using the row-standardized bidding matrix described in section 2. The dependent variable is the log of the adjusted bid value.

The results shown in Table 3 indicate that the Moran's I statistic is positive and statistically significant for the period of the alleged ICD bid-rigging operation (column (1), suggesting complementary bidding in the first stage of the procurement auction) and is not statistically significant and close to zero for the period in which the bid-rigging cartel was not supposed to operate (column (2)). Thus, the applied economic screen accurately captures the coordinated behaviour when the alleged cartel probably existed and does not capture the

coordinated behaviour when the alleged cartel probably did not exist. The evidence from Table 3 is similar the results of Lundberg's (2017) study, which analysed a Swedish asphalt bid-rigging cartel and applied Moran's I statistic for two different time intervals. There, the screen pointed to the existence of the cartel only in the period in which the scheme was effectively observed. Therefore, the screen based on Moran's I statistic to detect bid-rigging cartels seems to work well, even in different institutional contexts.

5.2. Robustness Checks

Column (2) of Table 3 shows that our screen does not indicate coordinated behaviour after the leniency agreement was made. However, the cartel firms may have incentives to maintain the collusive scheme in the short term to reduce damages, even after the cartel has been discovered (Erutku 2012). Another possibility is that the cartel discontinues the practice in the period immediately after the leniency agreement and returns to coordination after some time. In these situations, the estimated Moran's I statistic for the post-cartel period would be underestimated and incorrectly suggest that there is no coordination between firms in the post-cartel period. To reduce these concerns, we calculated the Moran's I statistic for the post-cartel period by removing the supposed transition periods from the database (we assume a transition period of three, nine or twelve months after the leniency agreement). Table 4 presents the results.

Table 4 – Bid Regression in post-cartel period: eliminating transitional periods

	6 months	9 months	12 months
	(1)	(2)	(3)
Intercept	-1.314**	-1.177	-2.442
	(0.687)	(0.72)	(2.154)
Capacity Rate	0.172***	0.1752***	0.1904***
	(0.058)	(0.060)	(0.068)
log (Employees)	0.385**	0.338*	0.701
	(0.198)	(0.21)	(0.64)
Number of Competitors	0.1265***	0.1323***	0.1435***
	(0.023)	(0.024)	(0.027)
Number of Items	-0.0001	-0.0001	-0.0001
	(0.000)	(0.000)	(0.000)
ICD Fixed-Effect	Yes	Yes	Yes
Firm Fixed-Effect	Yes	Yes	Yes
Procurement FE	Yes	Yes	Yes
F-Test	11.28***	8.01***	7.701***
Adjusted R^2	0.5026	0.4002	0.4067
Moran's-I Statistic	0.024	0.021	-0.027
Number of Observations	978	936	734

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors in parenthesis. Regressions are stimated using only the post-cartel period and removing transition periods. We assume transitional periods of three months (column (1)), nine months (column (2)) and twelve months (column (3)). The Moran's I statistic is calculated using the row-standardized bidding matrix described in section 2. The dependent variable is the log of the adjusted bid value.

As seen in Table 4, the Moran's I statistic remains not statistically significant for the post-cartel period, suggesting that possible transition periods do not seem to be relevant to our results.

To check the robustness of the results, we also tested the hypothesis of conditional independence using economic screens that are different from Moran's I statistic. The first one is based on Bajari and Ye (2003) and tests the possibility of bid coordination by checking whether the residuals of firm $i's$ bid function and the residuals of firm $j's$ bid function are correlated. Thus, it is a correlation test targeted at pairs of bidding sets of specific firms. Table 5 shows the number of simultaneous bids (for the same contracts) and the Pearson and Spearman correlation coefficients considering the six possible combinations of pairs of companies that were accused of bid-rigging in the ICD Brazilian market. The residuals were obtained by an OLS estimation considering the most complete specification of equation (2).

Table 5 – Pearson and Spearman correlation coefficients of bid residuals

Firms	N. Simultaneous Bids	Pearson Correlation	Spearman Correlation
[1,2]	1045	0.756***	0.486***
		(0.000)	(0.000)
[1,3]	711	0.677***	0.572***
		(0.000)	(0.000)
[1,4]	399	0.043	0.250***
		(0.390)	(0.000)
[2,3]	702	0.684***	0.464***
		(0.000)	(0.000)
[2,4]	408	0.226***	0.443***
		(0.000)	(0.000)
[3,4]	306	0.165***	0.254***
		(0.004)	(0.000)

Note: ***p < 0.01, **p < 0.05, *p < 0.1. *p-value* in parenthesis.

Table 5 reveals that in practically all pairs of simultaneous bids that were placed by the accused firms, the correlation coefficient is positive, and the hypothesis of no correlation is rejected (the only exception is the Pearson correlation coefficient that is associated with the set of bids of firm 1 and firm 4). Thus, this economic screen also points to the existence of systematic correlation between bids in the first phase of the procurement auctions of the Brazilian ICD market.

A second alternative way to test the hypothesis of conditional independence is to use the Bergman et al. (2019) approach and estimate the bid regression including a spatial lag in the dependent variable, which is a specification known as the Spatial Autoregressive Model (SAR):

$$b_{ic} = \rho \sum_{j=1}^{n} w_{ij} b_{jc} + \gamma X_{ic} + \theta_s + \lambda_p + \mu_i + \varepsilon_{ic} \qquad (3)$$

Here, b_{ic} is the adjusted bid, ρ is a parameter that captures the degree of dependence between the bids that are placed by type A firms, X_{ic} is a vector of observables variables that can affect our dependent variable and w_{ij} is the elements of the bidding matrix that is described in section 3. Thus, the dependence between bids (which suggests coordinating behaviour) can be evaluated by checking whether the spatial lag parameter (ρ) is statistically

significant. In this case, the interpretation would be that the bid that was placed by firm i is associated with the bid that was placed by the firm j after controlling for all the characteristics that were included in bid regression (3). Table 6 shows the estimated SAR using the maximum likelihood estimation. Column (1) presents the results restricting the data to the period in which the bid-rigging cartel was supposed to operate (2005-2015) and column (2) presents the results considering the post-cartel period (2015-2017).

Table 6 – Spatial Bid Regression for ICD public procurements using different subsamples

	Cartel Period (2005-2015)	Post-Cartel Period (2015-2017)
	(2)	(1)
ρ	0.4521***	-0.0343
	(0.013)	(0.026)
Intercept	1.5094***	-2.8472***
	(0.309)	(0.423)
Capacity Rate	-0.0548**	0.0661**
	(0.031)	(0.038)
log (Employees)	-0.3423***	0.5858***
	(0.040)	(0.086)
Number of Competitors	-0.0085	0.0860***
	(0.017)	(0.020)
Number of Items	-0.0003***	-0.0001
	(0.000)	(0.000)
ICD Fixed-Effect	Yes	Yes
Firm Fixed-Effect	Yes	Yes
Procurement FE	Yes	Yes
Log-Likelihood	-1672.609	-82.66346
AIC	4127.2	411.33
Number of Observations	3293	1386

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors in parenthesis. The dependent variable is the log of the adjusted bid value.

Column (1) of Table 6 indicates that ρ is positive and statistically significant, while column (2) shows that ρ is close to zero and is not statistically significant. This suggests that

the bids that are placed by the companies that were investigated for collusive behaviour are positively correlated and violates the conditional independence hypothesis only in the period in which the bid-rigging cartel is supposed to exist. Thus, both the screen based on correlation tests between pairs of bid regression residuals (Table 5) and the screen based on spatial bid regressions (Table 6) confirm our conclusions that were obtained using Moran's I statistic and reinforce the existence of autocorrelation between the bids that were placed in the first stage of the ICD procurement auctions.

6. Conclusions

In the present paper, we propose an economic screen that identifies the systematic correlation between bids to investigate the behaviour of an alleged bid-rigging cartel that operates in the Brazilian market for implantable cardiac devices. By applying Moran's I statistic to the residuals of the bid regressions and using the SIASG database, we show that the bids that were placed by the accused companies have systematic autocorrelation in the sealed phase of the electronic auctions, which suggests complementary bidding behaviour, which is a common characteristic of bid-rigging cartels. Additionally, in the period in which the alleged cartel probably existed (2005-2015), the Moran's I statistic captured the coordinated behaviour, and in the period after the leniency agreement (2015-2017), the proposed screen does not capture the coordinated behaviour. This result was robust to the elimination of transitional periods and the use of other alternative economic screens that checks the hypothesis of conditional independence in sealed auctions.

The main advantage of the economic screen based on Moran's I statistic is its low data requirements and computational and statistical simplicity. In addition, the screen is versatile and can be applied to any type of market where public procurement occurs using sealed auctions. However, Moran's I statistic requires prior knowledge of the identity of the companies that may form the bid-rigging cartel. Without information from documentary evidence, denunciations or leniency agreements, it becomes more difficult to construct the bidding matrix and to apply the screen. A partial solution to this disadvantage is to apply the economic screen to combinations of all sets of companies or apply it only to those with the largest market shares or to the most frequent bidders. Finally, another shortcoming of our

economic screen is the possibility of finding the existence of a bid-rigging cartel when one does not truly exist (false positives). This can occur when bids are correlated due to the existence of unobserved variables that influence the placed bids. Therefore, our screen cannot be used as isolated and definitive proof of the existence of a bid-rigging scheme and it is necessary to collect additional documentary evidence.

References

Abrantes-Metz RM, Bajari P (2012) Screens for conspiracies and their multiple applications. Compet Policy Int 8:177–193

Abrantes-Metz RM, Froeb LM, Geweke J, Taylor CT (2006) A variance screen for collusion. Int J Ind Organ 24:467–486. doi: 10.1016/j.ijindorg.2005.10.003

Abreu A (2018) Por dentro do cartel dos implantes. In: Piauí Folha

Aryal G, Gabrielli MF (2013) Testing for collusion in asymmetric first-price auctions. Int J Ind Organ 31:26–35. doi: 10.1016/j.ijindorg.2012.10.002

Bajari P, Ye L (2003) Deciding Between Competition and Collusion. Rev Econ Stat 85:971–989

Bergman MA, Lundberg J, Lundberg S, Stake JY (2019) Interactions Across Firms and Bid Rigging. Rev Ind Organ. doi: 10.1007/s11151-018-09676-0

Boyer M, Kotchoni R (2015) How Much Do Cartel Overcharge? Rev Ind Organ 47:119–153. doi: 10.1007/s11151-015-9472-1

CADE (2017) CADE's General Superintendence initiates administrative proceeding to investigate a cartel in the market of orthoses, prostheses and special medical supplies. In: Assessor. Comun. Soc.

Erutku C (2012) Testing post-cartel pricing during litigation. Econ Lett 116:339–342. doi: 10.1016/j.econlet.2012.03.033

Günster A, Carree M, Dijk M van (2011) Do Cartels Undermine Economic Efficiency? In: The American Economic Association

Harrington JE (2008) Detecting cartels. In: Buccirossi P (ed) Handbook of antitrust economics. London: MIT Press.

Imhof D (2017) Simple Statistical Screens to Detect Bid Rigging. Faculty of Economics and Social Sciences, University of Fribourg (Switzerland)

Imhof D, Karagök Y, Rutz S (2018) Screening for bid rigging-does it work? J Compet Law Econ 14:235–261. doi: 10.1093/JOCLEC/NHY006

Ishii R (2009) Favor exchange in collusion: Empirical study of repeated procurement auctions in Japan. Int J Ind Organ 27:137–144. doi: 10.1016/j.ijindorg.2008.05.006

Jakobsson M (2007) Bid Rigging in Swedish Procurement Auctions. Department of Economics, Uppsala University, Sweden

Lundberg J (2017) On cartel detection and Moran's I. Lett Spat Resour Sci 10:129–139. doi: 10.1007/s12076-016-0176-4

Mattos C (2014) Modalidades de licitação e cartéis no Brasil. Consult Legis da Câmara dos Deputados 1–17

Moran PA (1948) The interpretation of statistical maps. J R Stat Soc Ser B 10:243–251

Ragazzo C, Silva RM (2006) Aspectos econômicos e jurídicos sobre cartéis na revenda de combustíveis: uma agenda para investigações

Vasconcelos S, Vasconcelos C (2005) Investigações e obtenção de provas de cartel: porque e como observa o paralelismo de conduta. Ensaios FEE 26:1–20