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

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RESUMO:

Em 2015, um suposto cartel de licitações que operava no mercado de dispositivos médicos implantáveis foi divulgado e as autoridades públicas passaram a investigá-lo. O presente trabalho avalia se há correlação sistemática entre os lances ofertados pelos competidores na fase selada das licitações, uma situação que poderia sugerir a existência de um comportamento coordenado e fraudulento. Aplicando a estatística I-Moran aos resíduos de uma regressão de lances controlada e usando uma base de dados pública e inédita, nós mostramos que os lances ofertados pelas empresas investigadas possuem uma autocorrelação positiva e estatisticamente significante. Além disso, quando separamos nossos dados em dois subperíodos: período em que o cartel provavelmente existiu (2005-2015) e período em que o cartel provavelmente não existiu devido a celebração de um acordo de leniência (2015-2017), a estatística I-Moran é estatisticamente significante apenas na primeira subamostra. Os nossos resultados se mantiveram robustos a eliminação de períodos de transição e a aplicação de filtros econômicos alternativos. Por fim, nós também discutimos as principais vantagens e desvantagens práticas para a implementação do filtro baseado na estatística I-Moran.

Palavras-Chave: Cartel em Licitações, Econometria Espacial, Leilões Públicos, Cartel e Colusão, Política da Concorrência.

Área Temática: Microeconomia, Métodos Quantitativos e Finanças

ABSTRACT:

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 placed by competitors in the sealed phase of procurement auctions, a situation that may suggest a coordinated and fraudulent behavior. Applying the Moran´s I statistic to residuals of controlled bid regressions and using a novelty and public database, we show that the bids placed by the investigated companies have a positive and statistically significant autocorrelation. In addition, when we break the data into two subperiods: 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 due to elimination of transitional periods and the use of alternative economic screens. Finally, we show the main practical advantages and disadvantages for the implementation of the screen based on Moran´s I statistic.

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

JEL Classification: D44, H57, L44

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 the value of public procurement account for an estimated 15% of gross domestic product (GDP) worldwide on average according to OECD (2009) and the cartel overcharge around 16% (Boyer and Kotchoni, 2015), bid-rigging schemes can roughly provoke an economic loss 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, to reduce incentives for innovations (measured by investment in R&D), as evidenced by Günster et al. (2011).

For these reasons, the detection and fighting bid-rigging cartels has become a priority activity by 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 occurs an anonymous complaint or when a cartel member makes a delation, situation that is materialized in leniency programs. Although it is an efficient strategy, leniency agreements have the limitation of detecting only those cartels that are unstable and are close to a breaking point, so that successful cartels remain unscathed (Abrantes-Metz and Bajari, 2012). Therefore, 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 proactive practice is the use of economic screenings. Economic screenings 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 a non-competitive behavior[1].

In the present paper, we use an economic screening that identifies systematic correlation between bids to investigate the behavior of a bid-rigging cartel. More specifically, we follow the methodology recently proposed by Lundberg (2017), in which the 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-ringing cartel that operates in the implantable cardiac devices (ICD) market in Brazil. This bid-rigging scheme is under investigation 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 territory and comprises 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 screen to detect cartel behavior in public procurements. One tool traditionally employed is the variance screen. It is expected that the variance of the bid's 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 threshold of contract value, which tends to be higher than the contract value in case of competition. This practice restricts the possible universe of bid values (truncates the distribution) and, consequently, reduces 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 road construction sector in Switzerland also apply the variance screen as one of the stages of the cartel detection, claiming that this statistic is easy to implement due to 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

[1] As emphasized by Harrington (2008), the objective of economic screenings is to identify markets with high probability of collusion. Thus, the screens do not definitively prove the existence of a cartel and, like any other statistical test, may point to 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.

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

In addition to a smaller variance and bids interdependence, another common characteristic of bid-rigging cartels is the rotation of winners. The rotating behavior of cartel consists in the artificial exchange in relation to the winning bidder in procurement auctions that are frequently by the public administration. The study of Ishii (2009) analyzed this behavior in a detailed way. Using data from public procurements of Naha city (Japan) for consulting works service, Ishii (2009) showed that the variable that measures the score of favor exchange 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 favor exchange with a rotational scheme. Imhof (2017) and Imhof et al., (2018) also proposed a graphical analysis of the bids that allows to check the existence of rotating behavior in pairs of competing companies.

Considering this empirical literature of economic screens applied to bid-rigging cartels, we intend to contribute in two ways: I) by applying a methodology that allows to test the conditional independence hypothesis in a more flexible manner in relation to previous studies and II) by analyzing the behavior of a investigated bid-rigging that operated in the Brazilian market of implantable cardiac devices using a novelty and public database. It should be noted that, to our best knowledge, there isn’t 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 that operated in the ICD market and describes the main rules of the 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 summarizes the main practical advantages and disadvantages of applying our screen.

2 – Institutional Background

2.1 – Description of the supposed bid-rigging cartel

To evaluates the suitability of the screen based on Moran´s I statistic, we will analyze a supposed bid-rigging scheme that operated in the Brazilian market of implantable cardiac devices[2] (ICD). The disclosure of the alleged bid-rigging cartel began in January 2015, when the Ministry of Health - the public agency that makes the purchase of medicines, medical prostheses and hospital equipment for the provision of public health services – made a set of complaints pointing to frauds involving the ICD suppliers. Initially, there were indications that ICD procurements auctions were being frauded by the observation of the following practices: identical allocation of contracts, bidding only for contracts that would be effectively won, and 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 the bid-rigging scheme in the ICD market and committing to collaborate with investigations. Due to the collaboration, the company obtained a reduction in administrative and criminal penalties. After the conclusion of the leniency agreement, the competition authority made search and seizure operations at the headquarters and offices of the companies involved and gathered more robust evidence about the existence of the bid-rigging cartel. Among the collected evidences, stands out a document created by the set of companies that contains a schedule with the indication of 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). The scheme was coordinated through face-to-face meetings involving company directors and, in some situations, were intermediated by industry associations. Public managers and physicians also participated in the bid-rigging scheme by facilitating the frauds of public procurement auctions and simulating the need for ICDs in exchange of bribes provided by the companies.

The anticompetitive practices investigated are the following: exchange of price information, supply agreements, customers allocation between competitors and combinations of proposals in the phase of sealed bidding. 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 created for the purchase of ICD items are mostly carried out in the electronic modality[3] and are governed by the rules of Brazilian Enactment 5.450/2005. In the electronic modality, the public procurements take place virtually and has 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, functioning like as a sealed-bid auction. Following the opening of envelopes, the second stage of the acquisition process starts with a downward oral auction (with simultaneous bids) starting from the bid's values 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 presents the lowest bid in the second phase. Another important feature of 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 becomes more difficult to discover possible deviations from the collusive agreements.

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[2] The implantable cardiac device market involves the following items: (I) Implantable Dual-chamber and Unicameral Defibrillator Cardioverter (II) Cardiac Resynchronizer, (III) pacemakers - and accessory items - which include (IV) Endocardial Electrodes Temporary and Definitive, (V) Sets of Introducers and (VI) Catheter.

[3] Only 18 of the 1351 ICD contracts that we analyzed were taken in the live auction modality.

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

3 – Methodology

Before calculating the Moran´s I statistic, it is necessary to construct a weighting matrix (also called 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 has a construction similar to the 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 bids placed among type B firms and across type A and type B firms tend to be independent. Complementarity of bids is a strategy that simulates competition and is commonly adopted by bid-rigging cartels. It is characterized when a firm (previously defined by cartel members) bid lower to win the procurement auction while other cartel members offer higher bids in exchange for future rewards, such as subcontracting, consortium formation, or auctions victory, for example. In the context of the Brazilian ICD procurement auctions, complementary bidding in the first stage of the electronic auction can be an optimal strategy to manipulate the final auction outcome (see subsection 2.2) and allows a potential overcharge in contracts.

Denote by b_{ic} the bid value placed by firm i on contract c, n_a the number of bids placed by companies of type A, n_b the number of bids placed by companies of type B and n_c is the total number of bids that is equal to the total number of observations $N = n_c = n_a + n_b$. 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 the matrix $\boldsymbol{W}$ 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 relating to the contract c. This adjustment allows us to obtain a row standardized matrix. There are situations in which the identity of the companies participating in the 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 programs, 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 a complementary bidding behavior - which may indicate the existence of a bid-rigging scheme - the next step is to calculate the global Moran´s I statistic, developed by Moran (1948) and widely used to detect the existence of spatial autocorrelation. The global Moran´s I statistic is obtained by calculating the following expression:

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

Where $w_{ic,jc}$ is the elements of bidding matrix $\boldsymbol{W}$ described above, b_{ic} is the bid value placed by firm i on contract c, b_{jc} is the bid value placed by firm j and, finally, μ is the average bid value. Under the hypothesis of absence of autocorrelation, it is possible to demonstrate that the expectation of Moran´s I statistic is given by $E(I) = -1/(N-1)$, tending to zero to the extent that $N \to \infty$. To detect if there is autocorrelation between the bids, the null hypothesis $H_0: I = -1/(N-1)$ is confronted with the alternative hypothesis $H_a: I \neq -1/(N-1)$. If the null hypothesis is rejected, the Moran´s I test points to

the existence of autocorrelation between the bids. In this case, there is evidence that companies are adopting a bidding complementarity behavior in a systematic way, 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 have autocorrelation in sealed auctions due to natural market factors, not necessarily related to collusive behavior. For example, bids tend to be correlated when the different companies participating in the procurement auction have a similar cost structure, operate in the same geographic market, have a similar scale of production or when the bidding process occurs for the supply of goods and services in a specific area. In these situations, the 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 the Moran´s I statistic to the residuals of the following bid regression:

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

Where b_{ic} is the dependent variable and X_{ic} is set of controls that captures observable variables (company-specific and contract-specific) with potential to influence the magnitude of the placed bids. In addition to the observable variables, the bid regression can be estimated by including unobserved fixed-effects 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 the Moran´s I statistics on the residuals of equation (2), a potential systematic correlation between the bids can be attributed to another unobservable variables, which include the collusive behavior.

4 - Data and Descriptive Statistics

The database used in the present study is public and were obtained through the Integrated Administration and General Services System (Comprasnet - SIASG) of the Brazilian Federal Government. In this platform, the public administration operates and retains information regarding its purchase and contracts. This includes the registration and disclosure of public procurements, the correspondent record of prices and supplier's identity and the registration and management of contracts. Considering our objective, we filtered this database to get information from the procurement auctions related to the Implantable Cardiac Devices (ICD) market and involving the participation of at least one of the firms investigated for bid-rigging collusion.

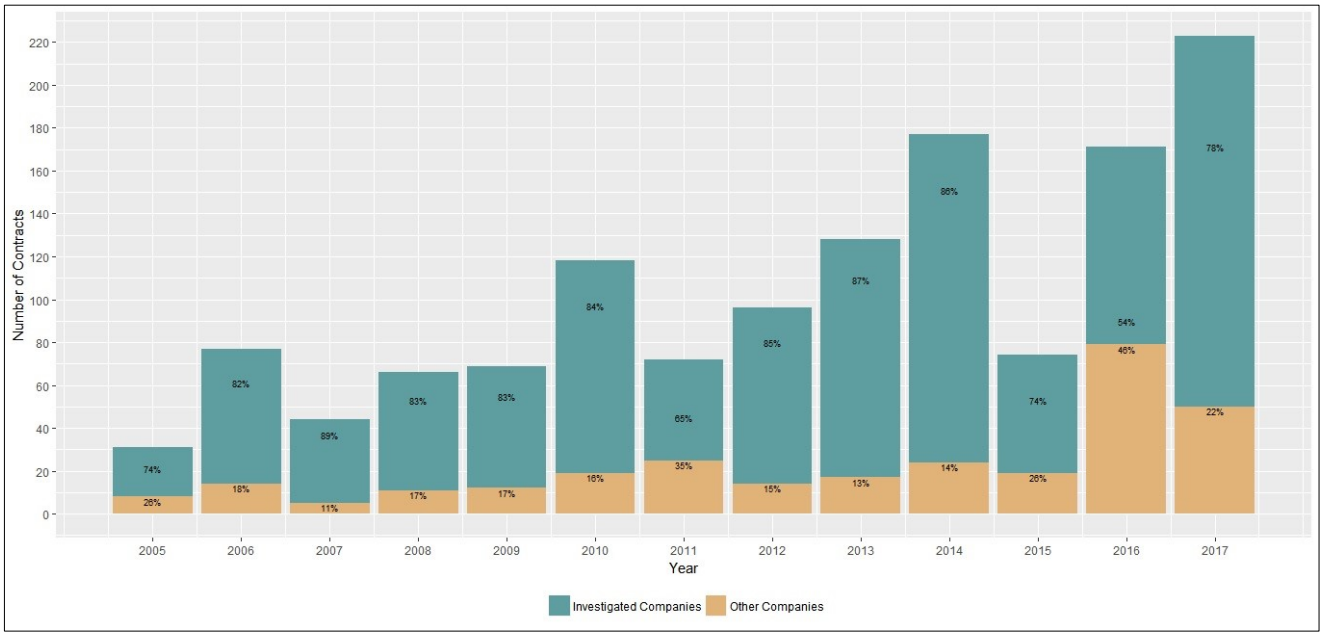
Thus, we obtained a dataset contain information on 238 public procurements involving 1351 different contracts[4] and 4679 bids submitted by 147 companies in the period from January 2005 to December 2017. The following information is available in our database: date of public procurement, identity of bidders, auction modality (electronic or live mode), municipality and public agency responsible for purchase, product code[5], product specification, bid values placed in the first stage of the auction, value estimated[6] by the public administration, number of demanded items, 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 won by the four companies investigated by bid-rigging collusion.

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

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

[6] 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.

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



Note: Own elaboration based on SIASG data.

We note that there is a strong variability in the number of contracts 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 that the companies investigated by bid-rigging cartel have substantial participation in the ICD market, with participation varying from 54% to 89% per year.

Regarding the variables used in the bid regression estimation, our dependent variable will be measured as the ratio between the bid value placed in the first stage of electronic auction and the correspondent bid value estimated by the public administration. This adjustment by the estimated bid value is important to eliminate the effect generated by bidding for a common target, which would generate a 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) Capacity Rate of firm i: is defined as the ratio between the number of contracts won by the firm up to the date of the contract c and the total number of contracts to be obtained until the end of the year in question; II) Number of employees of firm i; III) Number of competitors participating in the procurement auction associated to contract c, and IV) Number of ICD items to be contracted by the public administration through the contract c. The number of employees of 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 restricted to the period in which the bid-rigging cartel was supposed to operate (January 2005 to October 2015) and for the subset 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 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 devices market.

5 – Results

5.1 – Main Results

Table 2 shows the results of the estimation of equation (2) by Ordinary Least Squares (OLS) using three different specifications. The first one (column (1)) considers only the inclusion of 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 applied to the residuals of the bid regressions is showed at the bottom of the Table 2. As can be seen, independent of the specification, the Moran's I statistic is positive and statistically significant. This evidence indicates that the bids placed by the companies investigated by bid-rigging cartel in the ICD market have positive autocorrelation, violating the hypothesis of conditional independence. In practical terms, this positive correlation between bids of different competitors in the first stage of the electronic auction (which are governed by a sealed auction design) can suggest the existence of a coordinated scheme characterized by complementary bidding. Thus, our economic screen captures exactly what was identified by the documentary evidences 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 bidding. However, this counterintuitive relationship does not hold in the most complete specifications (column (3)). The log of number of employees (*proxy* for firm size) and the number of items that are demanded in each contract also negatively affect the value of 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, an expected result. The number of competitors of a specific contract does not affect the behavior of companies in ICD procurement auctions.

Table 3 shows the estimates of our bid regression and the Moran's I statistic separated for two data periods: the period from January 2005 to October 2015 (period in which there is documentary evidence of the operation of bid-rigging scheme) and the period between November 2015 and December 2017, where it is likely that the bid-rigging cartel 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 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 coordinating behavior when the alleged cartel probably existed

and does not capture the coordination behavior when the alleged cartel probably did not exist. The evidence from Table 3 is similar the results of Lundberg (2017) study, which analyzed an Swedish asphalt bid-rigging cartel and applied the Moran's I statistic for two different time intervals and 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 statistics 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 a coordinating behavior after the leniency agreement has been made. However, the cartel firms may have incentives to keep 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 suggesting 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 the 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 estimated 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 can be 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 change our results.

To check the robustness of the results, we also tested the hypothesis of conditional independence using economic screenings different from the 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 residuals of firm $j's$ bid function are correlated. Thus, it is a correlation test targeted to pairs of biddings sets of specific firms. Table 5 shows the number of simultaneous bids (which disputed the same contracts) and the Pearson and Spearman correlation coefficients considering the six possible combinations of pairs

of companies accused of bid-rigging cartel in the ICD Brazilian market. The residuals were obtained by 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 pair of simultaneous bids 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 associated with the set of bids of firm 1 and firm 4). Thus, this economic screen also points to the existence of a systematically correlation between bids in the first phase of the procurement auctions of Brazilian ICD market.

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

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

Where b_{ic} is the adjusted bid, ρ is a parameter that captures the degree of dependence between bids placed by type A firms, X_{ic} is a vector of observables variables that can affect our dependent variable and w_{ij} are elements of the bidding matrix described in section 3. Thus, the dependence between bids (which suggests a coordinating behavior) can be evaluated by checking whether the spatial lag parameter (ρ) is statistically significant. In this case, the interpretation would be that the bid placed by firm i is associated with the bid placed by the firm j, controlling for all characteristics 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).

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 bids placed by companies investigated for collusive behavior 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 obtained with the Moran's I statistic and reinforce the existence of autocorrelation between the bids placed in the first stage of the ICD procurement auctions.

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

	Cartel Period (2005-2015)	Post-Cartel Period (2015-2017)
	(1)	(2)
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.

6 – Conclusions

In the present paper we propose an economic screening that identifies systematic correlation between bids to investigate the behavior of alleged bid-rigging cartel that operates in the Brazilian market of implantable cardiac devices. Applying the Moran's I statistic to residuals of bid regressions and using the SIASG database, we show that bids placed by the accused companies have a systematic autocorrelation in the sealed phase of the electronic auctions, which suggests a complementary bidding behavior, 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 coordinating behavior and in the period after the leniency agreement (2015-2017), the proposed screen does not capture the coordinating behavior. This result was robust to 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 the low data requirements and the computational and statistical simplicity. In addition, the screen is versatile and can be applied to any type of market where the public procurements are governed by sealed auctions. However, the Moran's I statistic requires prior knowledge regarding 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 proceed with screen application. A partial solution to this disadvantage is to apply the economic screen to combinations of all sets of companies or apply only to those with the largest market share or to the most frequent bidders. Finally, another shortcoming of our economic screen is the possibility of pointing to the existence of a bid-rigging cartel when it does not really 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 an isolated and definitive proof of the existence of the bid-rigging scheme and makes necessary to collect additional documentary evidence.

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