WIDER Working Paper 2022/42

Anticompetitive practices on public procurement

Evidence from Brazilian electronic biddings

Adilson Sampaio,[1,3] Paulo Figueiredo,[1] and Klarizze Puzon[2]

April 2022

United Nations University World Institute for Development Economics Research

wider.unu.edu

Abstract: Using big data from the Brazilian public procurement system, this research aims to investigate what factors are associated with the occurrence of anticompetitive practices in electronic bidding. Our analysis considers all services contracted between 2014 and 2017. The study uses the logit regression model with a dependent binary variable to model the probability of bidding fraud as a function of a vector of explanatory variables composed of the characteristics of the bidding process and of the supplier, in terms of firm size, thus quantifying the relationship between the explanatory variables and the probability of fraud occurrence. We find that firm size and the Apparent Overbilling Index which we propose are associated with the occurrence of fraud and anticompetitive practices in electronic auctions. This study contributes to the accumulation of empirical and theoretical knowledge, expanding safer bases for governments and society in the fight against corruption.

Key words: anticompetitive practices, public procurement, bidding fraud, electronic bidding

JEL classification: C12, D73, H57

Note: As the research is part of one of the authors' PhD thesis, the authors will hold copyright to facilitate its publication.

---

[1] Federal University of Bahia UFBA, Salvador, Brazil; [2] UNU-WIDER, Helsinki, Finland and CERE, Umeå, Sweden, [3] Oswaldo Cruz Foundation FIOCRUZ, Salvador, Brazil; corresponding author: adilson.sampaio@fiocruz.br

1   Introduction

In September 2015 world leaders met at the United Nations (UN) headquarters to decide on an action plan called *Transforming our World: The 2030 Agenda for Sustainable Development* to eradicate poverty, protect the planet, and ensure that people achieve peace and prosperity. The document contains a set of 17 Sustainable Development Goals and includes the aim in goal 16.5 to 'substantially reduce corruption and bribery in all their forms' (UN 2015).

According to the United Nations Convention Against Corruption (UNCAC 2004: iii), 'corruption is an insidious plague that has a wide range of corrosive effects on societies. It undermines democracy and the rule of law, leads to violations of human rights, distorts markets, erodes the quality of life and allows organized crime, terrorism and other threats to human security to flourish'.

According to Köbis et al. (2021), corruption is one of the two greatest challenges facing society in our time. There is new hope that artificial intelligence (AI) will serve as an impartial anti-corruption agent. Every time we have more government data (openings), allies, or improved performance from previous algorithms, we move AI to the next frontier in the fight against corruption.

In recent years government authorities have increasingly used the internet for public procurement processes with the main objective of improving 'the quality of public spending', promoting access, competition, impartiality, and transparency, and allowing control by civil society (Sampaio et. al 2022: 5).

Availability of government procurement data is a commitment signed by the Brazilian government in the Open Government Partnership. The government is committed to promoting transparency in public spending, providing value-added information to society, and encouraging research and technological innovation through the implementation of the Brazilian policy on open data (Brazil Communication Company 2017).

According to de Pinho (2008), due to the advancement of technology, it is understood that e-government should not be seen only through the provision of online services but also through the wide range of interaction and participation possibilities between government and society and for the commitment of transparency on the part of governments.

The anti-corruption capabilities of public e-procurement, particularly automation and auditing capabilities, can increase the transparency and accountability of the government procurement process (Neupane et al. 2012a).

According to the OECD (2008) electronic contracting plays an important role in minimizing the risk of corruption in public contracts.

The fight against corruption in recent years has been established by the European Union as one of the main objectives of modern regulation and public procurement policy (Miranzo Diaz 2017). Corruption has already become the main concern when compared to issues such as the effects of globalization, the decline of social values, the negative impact of immigration, and the consequences of the accelerated pace of technological innovations, according to research by Edelman Intelligence published by the OECD (2018).

Sacramento and de Pinho (2018) contend that it is no exaggeration to state that the dominant perception in Brazil about corruption is that this phenomenon has assumed a systemic character

in the country. This understanding, which may be a consequence of the almost daily exposure of scandals involving the state powers and private organizations in all spheres of government, has dominated the reports and research published by institutions which carry out this type of measurement, such as the Corruption Perception Index (CPI), a ranking created by the non-governmental organization Transparency International.

In this research the term corruption is used for all types of behaviour in which a person who is in a position of trust misuses that position for their own benefit. In its procurement guidelines the World Bank defines a 'corrupt practice' as 'offering, giving, receiving or soliciting, directly or indirectly, anything of value to influence the action of a government official in the procurement or contract process' (Lengwiler and Wolfstetter 2006: 412). The approach to the political economy of antitrust used by Vachris (1996) is grounded in public choice theory which acknowledges that policies are determined by private rather than public interests.

Traditional approaches based on creating more rules, stricter compliance, and stricter enforcement have limited effectiveness. A strategic and sustainable response to corruption is public integrity. The concept of integrity, as used in the research, has been defined by Brazil's Controller General of the Union (CGU) as the quality of those who behave correctly, honestly, and against corruption.

According to the OECD (2018) public integrity refers to the consistent alignment with and adherence to common values, principles, and ethical standards to support and prioritize the public interest over private interests in the public sector. Therefore it must be understood as the set of institutional arrangements which aim to ensure that the public administration does not deviate from its main objective to deliver the results expected by the population in an adequate, impartial, and efficient manner. Integrity is one of the main pillars of political, economic, and social structures and is therefore essential to the economic and social wellbeing and prosperity of individuals and society as a whole.

The European Anti-Fraud Office (OLAF 2017) is of the view that promoting integrity in public contracts by the various institutions, with the effective prevention of fraud, depends on observance of the principles of ethics and integrity. If these principles are less rigorously enforced, then fraud is more likely to occur. Preventive controls work by deterring fraud and corruption. There is a strong link between the incidence of fraud and corruption and weak preventive controls. In many cases where fraud and corruption are detected, it is possible that preventive controls have failed, allowing the incident to occur (TCU 2018).

According to Miranzo Diaz (2017) the approach to the problem of corruption which establishes the need for strategic decisions, the practical implementation of integrity principles, and their related concepts justifies the adequacy of promoting the implementation of anti-corruption measures.

For the OECD (2008) integrity in the context of public procurement implies that:

1) Procurement procedures are transparent and promote fairness and equal treatment for bidders;
2) Public resources linked to public purchases are used in accordance with the intended objectives;
3) The behaviour of procurement officials is in line with the public objectives of their organization; and
4) Systems are in place to challenge purchasing decisions, ensure accountability, and promote public scrutiny.

As a result of the previously mentioned availability of government procurement data, extracting data from the available databases becomes stimulating for social science researchers. We found that the amount tendered in the last five years is of the order of BRL260 billion, encompassing all types of bids from 557,567 procurement processes.

Most of the surveys in this Brazilian government's procurement database use data from acquisitions of materials and equipment and compare them with market prices, for example. Those which verify service contracts are rare due to the difficulty in finding similar market price parameters, perhaps because of the specificity of this type of contract. This type of gap is becoming an interesting venue for research.

According to Tóth and Hadju (2017), current studies address the risks of the occurrence of corruption and the value of free competition, and these should be complemented, for example, by integrity indicators of contracting entities. In addition to developing these indicators, further analysis options provided by existing indicators should be considered. As elementary data on public procurement is available, it can be analysed at any level of aggregation (e.g., enterprise groups, municipalities, administrative units, operational programmes).

The objectives of this paper are to analyse the participation of competitors in the electronic auctions of the Brazilian public procurement system held in a predetermined period, and to identify bidding and result patterns as well as factors that indicate the probability of the occurrence of fraud and anticompetitive practices. The aim is to answer the research question: 'Which factors are associated with the occurrence of fraud in the electronic public procurement system in Brazil?'.

The paper is divided into six sections. Following this introduction Section 2 presents the literature review and the theoretical framework. Section 3 discusses corruption and fraud indicators and sets out our hypotheses. In Section 4 the data collection and investigation methods are unveiled, followed by the results and the discussion in Section 5. Finally, Section 6 discusses the conclusions and practical implications and limitations.

2   Literature review

This section presents and discusses essential theories, arguments, and controversies in the field of corruption and highlights research already carried out, identifying gaps and choosing theoretical and methodological strategies focused on enlightening and helping to achieve the research objectives (Gray 2012). The literature review is therefore divided into three topics: anticompetitive practices, which is the theoretical framework of the research; anticompetitive practices in electronic biddings in the public sector—possible indicators of anticompetitive practices in electronic biddings in the public sector; and, finally, the theory which explains corruption and anticompetitive practices in public e-procurement auctions.

2.1   Anticompetitive practices

In Brazil the Administrative Council for Economic Defense (CADE—Portuguese abbreviation) defines anticompetitive conduct as 'any practice adopted by an economic agent that may, even if potentially, cause damages to free competition, even if the infringer has no intention to cause damages to the market' (CADE 2016). Market power by itself:

> ... is not considered illegal, but when a company or group of companies abuse this
> power by adopting a behaviour that harms free competition, then such behaviour

is considered an abuse of economic power. This abuse is not limited to a restricted set of specific practices, as the analysis about the possibility of a conduct causing damage to competition is complex and many factors must be analysed in order to determine whether a practice is an abuse or not. (CADE 2007: 28)

Brazilian antitrust policy is regulated by Law No. 12,529 of 30 November 2011, named the 'Competition Defense Law' or Antitrust Law. Brazil is one of the few countries that has a specially articulated system for the defence of competition. The Brazilian System for the Defense of competition is composed of three bodies: the Secretariat for Economic Monitoring of the Ministry of Finance (SEAE—Portuguese abbreviation), the Secretariat for Economic Development (SDE/MJ—Portuguese abbreviation), and CADE, an autarchy linked to the Ministry of Justice.

The SDE, through the Department of Economic Protection and Defense (DPDE—Portuguese abbreviation), is the body responsible for investigating violations of the economic order. The SEAE, in turn, is responsible for issuing economic opinions on mergers as well as, optionally, preparing opinions on investigations into conduct harmful to competition. CADE is a body composed of seven directors which makes the final judgement at the administrative level of violations of the economic order and verticalization initiatives based on the reports issued by SDE and SEAE (Federative Republic of Brazil 2008).

In this sense SDE considers 'collusion between bidders' or cartels in bidding as the most common forms of anticompetitive practices, leading to serious problems for the public administration and often resulting in corruption. These practices aim to restrict or eliminate rivalry between potential or de facto participants in a given bid, increasing the price at which the administration will contract a certain good or service and thus increasing the profit of the bidding and infringing companies.

The bidding cartels substantially harm the efforts of the Brazilian state to use its resources for the development of the country by unduly benefiting companies which, by means of agreement among themselves, defraud the competitive nature of the bids. Although the administration seeks to rationalize its purchases through stricter budget controls and improved forms of contracting, such as by using electronic auctions, this does not totally impede the actions of cartels which result in the undue transfer of income from the state to the companies (Federative Republic of Brazil 2008).

2.2 Anticompetitive practices in electronic bidding in the public sector

According to Albano et al. (2006), the emergence of 'bidding cartels' in acquisitions, i.e. collusive agreements in bidding processes, is driven by forces very similar to those that govern the formation of cartels in oligopolistic markets.

The electronic bidding system is seen as an instrument of efficiency in public procurement and contracting, bringing economy and speed to the process. But it is not free from fraud. The main types of such fraud are the use of computer programs which automate the submission of bids, the combination of prices between suppliers, the use of established companies with the aim of frustrating competition in disputes and favouring certain participants, and associations between public agents and suppliers in order to circumvent the legal procedure (Lima 2016).

Corruption necessarily involves a public official whose entrusted power is used for private gain (Transparency International 2018). Fraud, on the other hand, is characterized by public or private agents acting to obtain illicit advantages, concealing their decisions and their respective effects. Fraud and corruption, although similar to ethical violation, are different events (Jamal et al. 1995).

Fraud is the intentional action promoted for one's own benefit by an agent to the detriment of others, enforcing the law of least effort. Iudícibus et al. (2001: 96) conceptualize fraud in accounting as the act of cheating for one's own benefit, which can be characterized as theft, embezzlement, and falsification. In turn Costa and Júnior (2012: 465) conceptualize fraud as a set of illicit actions performed in a premeditated way by the authors which aim to meet their own interests but cause losses to the assets of others.

The risk of fraud and corruption is reduced if the 'buyer' organization knows well the third parties it is dealing with, especially for more significant purchases where the risk of receiving bribes and secret commissions is high (TCU 2018).

The electronic auction was created with the aim of facilitating bidding and ensuring greater competitiveness, enabling all interested parties to participate without having to travel to the venue. However, a major controversy regarding the electronic auction is the use of software by bidders. Some have AI and are called robots. These robots are used to immediately cover the bids that are offered, typically just pennies apart. As the ending of the bidding phase is random/abrupt, the winner ends up being awarded the contract through luck (Campana 2018).

Reverse auctions are an efficient mechanism, according to Lengwiler and Wolfstetter (2006). They have been used for centuries in the classic form, like auctions, and are being used more often. But reverse auctions can suffer from manipulation through collusion and corruption. According to Lengwiler and Wolfstetter (2006), 'collusion means that bidders coordinate their actions with the intention of raising the price. Corruption means that the person running the auction, the auctioneer, distorts the auction rules in favor of some bidder(s) in exchange for bribes' (Lengwiler and Wolfstetter 2006: 412). Corruption and collusion are sometimes intertwined (Iudícibus et al. 2001; Lengwiler and Wolfstetter 2006; Rose-Ackerman 1975).

The Federal Audit Court conducted an audit to analyse a series of improprieties in the conduct of companies participating in public tenders conducted by means of electronic bidding by the federal government. Two situations were specifically analysed: companies with partners in common submitting proposals for the same item in the same bid and the existence of bidders repeatedly disqualified for not complying with the call for tenders or not honouring their proposals. In a previous audit which analysed bids that took place between 2006 and 2010, the Court of Audit of the Union (TCU—Portuguese abbreviation) found evidence of irregularities in 16,000 cases in which at least two companies bidding for a certain item in the tender had at least one partner in common. At the time it was also found that there were 31,000 companies which had submitted the lowest bids in the auctions—and, therefore, won the bid items—but, when summoned by the auctioneer to submit their qualification documents, gave up on the bid. The estimated value of the contracts where these problems were identified was BRL4.6 billion (Telesintese 2015).

Hanák (2018) considers that when certain principles and limitations are respected, the electronic auction can be used successfully for the acquisition of goods, services, and works.

According to OECD (2016), when considering the public procurement technique around indicators of a good public purchase, one must consider integrity risks in the procurement process.

As previously mentioned, collusion between participants can also occur, cartels can be formed, and robots can be used to distort auction results.

In 2006 the federal police launched Operation Leech to dismantle a bid-rigging scheme in the health sector. The gang had been negotiating with parliamentary advisers for the release of individual amendments to the union's budget for specific municipalities. With guaranteed

resources the group manipulated the bidding and defrauded competition using front companies, meaning that the bidding prices were overpriced. The group became known as the 'ambulance mafia' or 'leech mafia' (Aranha 2015).

According to Rebouças et al. (2017), in Brazil, the electronic auction in the Comprasnet system provides businesses with millions of reais every year, and companies which supply services and products may be using this as an opportunity to carry out transactions aimed at higher profits, sometimes in an illicit manner. Investigations found that, in the three years up to 2017, criminal practices by a group of businessmen to systematically defraud purchases made through Comprasnet and other contests had been detected. The organization colluded for price fixing and bid rigging. The federal agencies with damaged bids included the Brazilian Army, the Federal Institute of Mato Grosso do Sul, the Superintendence of Administration of the Ministry of Finance, and the Federal Superintendence of Agriculture. In just one of the bids, the investigation found a 600 per cent premium in the unit value of the products purchased due to the intervention of the criminal organization. The values offered by the winners were previously adjusted, preventing free competition and resulting in losses to the Treasury (Congresso em Foco 2017)

According to studies by Miroslav et al. (2014), the main problems in the public sector e-bidding process are the inadequate application of regulations and the high level of corruption. They explored the work of analysts who identified three phases of procurement where corruption usually occurs: the planning phase, definition of estimation criteria, and the realization phase. They proposed introducing semantic technologies into the process to enable data manipulation by machines which could enable experts to propose red flags under specific conditions in order to be alerted about possible irregular procurement. According to these authors the application of the proposed solution should enable early recognition of potentially irregular acquisitions.

2.3 Theory explaining corruption and anticompetitive practices in public e-procurement auctions

This paper aims to present a theoretical model to guide electronic bidding based on the theoretical fields of the economics of corruption and public choice, establishing a more assertive model for analysing electronic bidding systems. The models so far have been conceived without a specific supporting theory. Here we address the complexity of the relationship between the variables involved and their possible influence on the indication of abnormalities. The supporting theories also include principal-agent and antitrust theories, considered here as transversal to the problem and organized according to Table 1.

Table 1: Main concepts related to the problem (theoretical and practical references)

Theory/concept	Database			
	SPELL	CAPES	GOOGLE Scholar	SCIELO
	References			
Public choice	Becker (1968), Colebatch (2002), De Rond and Thietart (2007), Miles (1978), Nollet (2005).			
Economics of corruption	Acemoglu (2004), Ades and Di Tella (1997), Becker (1968), Lengwiler and Wolfstetter (2006), Rose-Ackerman (1975, 1996, 2014), Sacramento and de Pinho (2018) Søreide (2002), Tóth and Hadju (2017), Transparency International (2016).			
Principal-agent	Acemoglu (2004), Donahue (1989), Heath and Norman (2004), Neupane (2012a, 2012b, 2014), Setyadiharja et al. (2014), Vachris (1996).			
Antitrust	Hay (1985), Howard et al. (2002), Huber et al. (2004).			

Source: authors' compilation.

Public choice

Public choice theory uses economic instruments to solve problems in political science. It is a branch of rational choice theory and is therefore positivist in nature. Gary Becker was one of the first to apply rational actor models more widely and in 1992 he won the Nobel Prize in Economics for his studies on discrimination, crime, and human capital.

For Becker (1968) individuals and the state optimize their utility functions, including in the case of illicit actions, by evaluating the cost/benefit ratio of their actions, finding an 'optimal point' of illegal practice—the individual evaluates the expected gain as a benefit and the expected penalty as a cost, while the state evaluates society's welfare (security) as a benefit and the expenditure on public safety, justice, and imprisonment as a cost.

According to Søreide 'the main reason for bribery in public procurement, however, is probably because everyone believes that everyone is involved in such business' (Søreide 2002: 4). Losing a contract because a competitor bribed you must be very frustrating. This problem of hidden information is reflected in the way that all companies involved pay a bribe, even if they would be better off without corruption (prisoner's dilemma) (Søreide 2002: 4).[1] Therefore firms which bribe the authorities seem oblivious to the negative externality they impose on other firms as well as to the worsening of their economic environment (Ades and Di Tella 1997; Becker 1968; Lee et al. 2019; Rose-Ackerman 1975; Søreide 2002).

The economics of corruption

The economics of corruption has its origins in the works of Becker (1968) and Rose-Ackerman (1975). Following Becker's line of reasoning Rose-Ackerman (1975) analyses corruption with a focus on the principal-agent model. In the model, the principal (government) delegates tasks to its employees (agents), who perform them subject to bribery proposals from those influenced by the

---

[1] The 'prisoner's dilemma' is one of the most famous examples of game theory application. Proposed by Flood, Dresher and Tucker in 1950, the game, in short, proposes a situation in which two players must choose between cooperating and not cooperating simultaneously. If both players cooperate the payoff is good for both players and has value B, if both players do not cooperate the payoff for both has value C, and, if the players make different decisions the one who cooperates has result D and the one who does not cooperate has result A. So that A > B > C > D. (Almeida and Chacha 2014: 38)

task. Also, according to Rose-Ackerman (1996), if the probability of detection and punishment is high, bribes may not be worth doing.

'Corruption' is understood to mean all types of behaviour in which someone in a position of trust misuses that position for their own benefit (Becker 1968; Iudícibus et al. 2001; Rose-Ackerman 1975). In its procurement guidelines the World Bank defines a 'corrupt practice' as 'the offering, giving, receiving, or soliciting, directly or indirectly, of any thing of value to influence the action of a public official in the procurement process or in contract execution' (cited in Lengwiler and Wolfstetter 2006: 412).

Also according to Rose-Ackerman (2014), in practice, any policy will benefit some and impose costs on others. Thus one cannot easily say that anything against the public interest is corrupt, because there is no overarching general will in a democracy which implies that a particular set of public policies and public choices need not be consistent with problems or over time.

In the context of this research, the author reflects that bribery, extortion, and fraud are the 'easy way'. Enriching oneself at the expense of taxpayers and citizens seeking to gain benefits or avoid costs is clearly contrary to the public interest. There is always a superior uncorrupted option that could improve everyone except those involved in the corrupt business (Rose-Ackerman 2014).

As the object of the economics of corruption is to study how wealth and the power of market forces can alter resource allocation decisions by influencing both market and non-market mechanisms, and to the extent that public procurement and bidding are market activities and are directly influenced by market forces, it lends itself to theoretical support for our research.

The theoretical contribution which we expect to result from our research is the verification that the search for corrupting state structures does not necessarily occur for the purpose of reducing bureaucratic obstacles to business, as pointed out by studies on the economics of corruption (Becker 1968; Lengwiler and Wolfstetter 2006; Rose-Ackerman 1975, 1996, 2014). This is because even in disputes that occur in electronic environments, i.e. with fewer bureaucratic business structures, reduced deadlines, and agile processes as in the case of electronic bidding, the actions of the corrupt may coexist in significant numbers and, if so, this will contradict the theory under analysis. One explanation for this is the occurrence of 'opportunism' which is present in the transactions, according to the theory of transaction costs.

Principal-agent

This theory is based on an agency model developed by economists and deals with situations in which the principal is in a position to induce the agent to perform tasks in the interests of the principal but not necessarily of the agent (Barngetuny and Kimutai 2015; Donahue 1989; Heath and Norman 2004).

Principal-agent theory was advocated by Donahue (1989:12). He stated that procurement managers in the private sector play a relationship role. But his findings are based on the buyer/supplier relationship and the need of the buyer, as the principal, to minimize the risks posed by the agent. The author argued that procurement managers including all civil servants concerned with public procurement must play the agent role. Therefore procurement managers take on the role of agent for elected representatives. The principal-agency theory holds that sabotage is likely to occur when there is some disagreement between policy makers and the bureaucracy (Donahue 1989: 12).

In this sense, when a group of agents such as public servants diverge from the principal (elected representative) or from the public policy, there may be a kind of favouritism of business groups which in the view of this group of agents is also in opposition to the principal. This explains why, in some cases of anticompetitive practices, corruption or fraud continue to occur even when there is government change. This theory helps to explain why entire public organizations, within the direct or indirect administration, can be 'made captive' by interest groups and favour illicit practices (Köbis et al. 2017; OECD 2009). This mechanism has been evident in recent cases such as the so-called 'Operation Lava-jato' in Brazil where entire public business sectors were co-opted by the so-called 'contractors' club'.

According to Acemoglu et al. (2004), different groups and individuals benefit from different economic institutions, and there is usually a conflict over these social choices which is resolved in favour of the groups with greater political power.

Principal-agent theory can be used to explain how anticompetitive practices can occur in the context of public procurement (involving public servants).

Antitrust

According to Chen (2021) antitrust laws are:

> ... broad laws that protect consumers and regulate how companies operate their businesses. The goal of these laws is to provide an equal playing field for similar businesses that operate in a specific industry while preventing them from gaining too much power over their competition. Simply put, they stop businesses from playing dirty in order to make a profit. (Chen 2021: 1)

Lee et al. (2019) point out that:

> While cooperation can be sustained by institutions that punish the corrupt, such institutions, however, tend to be subverted by corruption if they are not closely monitored. Monitoring can support the enforcement of binding agreements that ensure cooperation, but this usually comes at a price. The temptation to skip monitoring and take the integrity of the institution for granted leads to outbreaks of corruption and the breakdown of cooperation. (Lee et al. 2019: 13276)

On the other hand Gilauri (2017: 21) states 'that regulatory restraint is the best long-term precaution against the resurgence of corruption. By regulatory restraint [he means] a degree of regulation that maximizes growth and reflects the capacity of a government to enforce the rules it makes'.

Lee et al. (2019), Gilauri (2017), and Vachris (1996) verify that market concentration can influence the outcome of public bids in services such as telephony where the concentration is so great that companies belonging to the same holding company participate separately in auctions, in apparent 'competition'. The same thing occurs with the so-called manufacturer's representatives in the area of information technology, where, in bids for equipment, the manufacturer itself participates alongside several representatives.

Thus gaps in the antitrust legislation in Brazil, coupled with the lack of enforcement, contribute to the occurrence of anticompetitive practices in electronic auctions, which in turn destabilize the market sectors involved.

Antitrust theory can be used to explain how anticompetitive practices disrupt markets (involving companies). The antitrust political economy approach used by Vachris (1996) is based on public choice theory, which recognizes that policies are determined by private rather than public interests.

In this paper we focus on public choice theory and economics of corruption theory, with the aim of helping to understand the choices of companies in performing anticompetitive practices which are often motivated by two factors: their financial intentions and the lack of punishment.

3 Corruption and fraud indicators and hypotheses

Considering the public context in which there is the risk of collusion in public bids, De Souza and Louzada (2020) researched how to identify and combine the evidence obtained from computerized databases so that it is possible to recognize bids that are more likely to have been subject to collusion among bidders. The authors presented a methodological approach which enabled the identification and combination of evidence from the use of different data-mining techniques to recognize the bids in which collusion among bidders may have occurred. According to these authors, however, there are few studies which deal specifically with the detection of collusion in public bids.

3.1 Integrity indicators

By creating corruption detection indicators using data from Hungary's public procurement system, Fazekas et al. (2013) reveal that many regulatory interventions succeeded in changing the form of corruption but not its overall incidence. Rebouças et al. (2017), meanwhile, propose a model which uses indicators for the detection of fraud in federal government electronic procurement conducted through the Comprasnet system.

Corruption perception research originated from agencies specializing in investment risk analysis, including the International Country Risk Guide; the Economist Intelligence Unit, UK; Standard and Poor's, USA; and the Political Risk Service, USA. Based on surveys by these institutions, the anti-corruption organization Transparency International developed the Corruption Perception Index (CPI), which ranks the countries of the world according to the degree to which respondents perceive the level of corruption. The CPI is currently the subjective and aggregate measure of corruption most widely used in economic research (Campos 2012).

Table 2: Summary of previous empirical literature about fraud/corruption in public auctions

Author/year	Title of work	Model/methods	Contribution
Wensink and de Vet (2013)	Identifying and reducing corruption in public procurement in the EU	Probit – linear regression	Estimation of probability of corruption
Ferwerda et al. (2017)	Corruption in public procurement: Finding the right indicators		
Mencía et al. (2013)	Using data mining on linked open data for analysing e-procurement information	k-NN, LibSVM, LibLinear Ensemble, Neural network	A method for predicting the number of tenders

Wang (2016)	Detecting fraud in public procurement	One-class support vector machine, logistic regression	Predictive model of fraud risk in contracts
Gallego et al. (2021)	Preventing rather than punishing: An early warning model of malfeasance in public procurement	Lasso logistic regression, conditional inference tree, gradient boosting machine	Study of the prediction of malfeasance within contracts
Carvalho et al. (2011)	Using Bayesian networks to identify and prevent split purchases in Brazil	Tree-augmented network, Bayesian networks	Analysis of split purchases
Sales and Carvalho (2016)	Measuring the risk of public contracts using Bayesian classifiers	Naive Bayes, tree-augmented naive Bayes score-based learning algorithms	A predictive model of fraud risk in contracts
Sales (2013)	Risk prevention of public procurement in the Brazilian government using credit scoring	Logistic regression, decision tree	A predictive model of fraud risk in contracts
Sun and Sales (2018)	Predicting public procurement irregularity: An application of neural networks	A neural network, deep neural network, logistic regression, discriminant function analysis	Prediction models of public procurement irregularities designed for initial screening of contractors
Fazekas and Kocsis (2020)	Uncovering high-level corruption: Crossnational objective corruption risk indicators using public procurement data	Logistic regression, linear regression	Identified coefficients that represent the strength of association between each underlying likely corruption input and likely corruption outcome
Fazekas, Tóth, and King (2016)	An objective corruption risk index using public procurement data		
Ralha, and Silva (2012)	A multi-agent data mining system for cartel detection in Brazilian government procurement	Clustering, association rules, multi-agent approach	Analyse the relationship between companies, and cartel detection
Baldomir et al. (2018)	Brazilian government procurements: An approach to find fraud traces in companies' relationships	Association rules – A-priori algorithm	
Domingos et al. (2016)	Identifying IT purchase anomalies in the Brazilian government procurement system using deep learning	Deep learning auto-encoder algorithm	Anomaly detection
Sampaio et al. (2022)	Public procurement in Brazil: Evidence of fraud using the Newcomb-Benford Law (NB-Law)	Use of the Newcomb-Benford Law (NB-Law)	

Tas (2017)	Collusion detection in public procurement with limited information	The reduced form of linear regression enriched kernel-based regularized least squares method with the proposed approach	Uncovering the structure of collusive behaviour
Van Erven et al. (2017)	Graph database: A case study for detecting fraud in acquisition of Brazilian government	Graph databases, decision support system, rule-based	Identify relationships between companies
Carneiro et al. (2020)	Network analysis for fraud detection in Portuguese public procurement		
Arief et al. (2016)	Fraud detection based on data mining on Indonesian e-procurement system	Naive Bayes, Bayesian networks, decision tree, and neural network	Detection of fraud public in procurement processes
Modrušan, Rabuzin, and Mršić (2020)	Improving public sector efficiency using advanced text mining in the procurement process	Data mining, linear regression, support vector machines, Naive Bayes, process mining	Detection of suspicious public procurement processes
Rabuzin and Modrušan (2019)	Prediction of public procurement corruption indices using machine learning methods		
Decarolis and Giorgiantonio (2020)	Corruption red flags in public procurement: New evidence from Italian calls for tenders		
Modrušan et al. (2020)	Intelligent Public Procurement Monitoring System Powered by Text Mining and Balanced Indicators		
Velasco et al. (2021)	A decision support system for fraud detection in public procurement	Graph theory, clustering, and regression analysis with advanced data science methods	Study of the collusion between bidders, conflicts of interest, and companies owned by a potentially straw person used for disguising its real owner

Source: the authors, adapted from Table IV in Modrušan et al. (2020: 4).

The studies listed in Table 2 all focus on the issue of fraud detection in public procurement systems around the world, including studies on the Brazilian system. At least six of them (Fazekas and Kocsis 2020; Fazekas, Tóth and King 2016; Gallego et al. 2021; Sales 2013; Sun and Sales 2018; Wang 2016) use logistic regression for their analyses, demonstrating considerable use of this technique for studies in the field.

Brazil currently ranks 94th in the perception of corruption (CPI) measure (Figure 1). This reinforces the need to study the mechanisms that weaken the procurement system and open space for corruption.

Figure 1: Brazil's position in the CPI corruption perceptions ranking

Index 2020   Results table

Score	Country	Rank
38	Tanzania	94
38	Ethiopia	94
38	Peru	94
38	Brazil	94
38	Kazakhstan	94
37	Indonesia	102
37	Gambia	102
36	Vietnam	104

AMERICAS

BRAZIL

Score	Rank	Score change
38/100	94/180	⬇ -5 since 2012

Source: Transparency International (2021). CPI 2020 by Transparency International is licensed under CC BY 4.0. Available at https://www.transparency.org/en/cpi/2020

According to studies by Köbis et al. (2017), corruption in its major forms is a strong threat to the functioning of societies, and the most frequent cause of serious corruption is the metaphor of the slippery slope, i.e. the idea that corruption occurs gradually. However, disagreeing with this, the authors empirically tested whether acts of serious corruption happen gradually or abruptly. They conducted four experimental studies and indicated a higher likelihood of serious corruption when participants were directly given the opportunity to engage abruptly compared to when they had previously engaged in minor forms of corruption. This shows the pressing relevance of testing whether the breach of a possible agreement or collusion influences the probability of detecting a possible fraud.

3.2   Hypotheses from the theoretical framework

According to the OECD (2009) conspiracies among bidders can take many forms, any of which impede the efforts of procurement officials—often local and national governments—to obtain products and services at the lowest possible price. Bidders often define who will submit the bid to

be awarded through a bidding process. A common goal in a bid-rigging conspiracy is to increase the value of the winning bid and, consequently, the profit of the chosen bidders.

In this sense collusive bidding (or bid rigging) occurs when bidders, instead of competing as one would expect, 'secretly conspire to raise prices or lower the quality of goods or services for purchasers who wish to acquire products or services through a bidding process' (OECD n.d.).

Therefore the identification of overbilling, i.e. the contracting of prices far above market prices, may be an indication of irregularity. Also according to the OECD (2009), bid prices can help uncover collusion situations. Patterns should be looked for:

> ... that suggest that companies may be co-ordinating their efforts such as price increases that cannot be explained by cost increases. When losing bids are much higher than the winner's bid, conspirators may be using a cover bidding scheme. A common practice in cover pricing schemes is for the provider of the cover price to add 10 per cent or more to the lowest bid. Bid prices that are higher than the engineering cost estimates or higher than prior bids for similar tenders may also indicate collusion. (OECD 2009: 13)

As this reasoning involves the issue of the estimated value, we propose a new index: the Apparent Overbilling Index (AOI).[2] The index is obtained as a function of the ratio of the subtraction of the bidding value (BV) by the estimated value (EV), over the estimated value and could become an important tool to verify the probability of fraud having occurred.

Therefore, from this discussion, we extract the following hypothesis to be tested in this paper:

H1: The higher the AOI of the procurement process, the higher the probability that fraud has occurred.

According to Brazilian legislation designed to encourage the participation of small and micro enterprises (SMEs) in public procurement, (Law 123/2006), there is a bid reinforcement called 'fictitious tiebreaker'. This incentive allows an SME to win—after the auction has taken place—with an *ex-post* lower bid if the previous winning bid by a larger company was less than 5 per cent lower than the SME's actual bid during the auction. The studies conducted by Bajari et al. (2009), Silva and Ferreira (2007), and Sampaio (2012) considered this tiebreaker and its importance for the performance of SMEs in electronic procurement. The survey conducted by Sampaio (2012) found that this benefit was used in about 24 per cent of SME winning tenders, and therefore it would be interesting to verify the size of the companies that won the bidding and whether this was related to any possible evidence of a larger company colluding to circumvent the 'fictitious tiebreaker' system. If there are no SME winners in this universe or if the number is below that observed in the previous study, this may be an indication of larger firms colluding to remove the small ones from the dispute.

The practice highlighted by OECD (2018) in which companies in collusion tend to place bids at 10 per cent above the value of the lowest bid rules out use of the tiebreaker by SMEs. That said, the following hypothesis will be verified:

---

[2] In this paper, we propose the Apparent Over-billing Index (AOI), which consists of the following formula: (VL-VE) /VE, where VL = bid amount and VE = estimated amount, both considering the price per unit.

H2: The larger the size of the winning firm in the electronic auction, the higher the probability that fraud has occurred.

4   Methods and approach

The methodology used in this paper consists of an exploratory empirical–inferential analysis of the data contained in the federal government's Purchasing Portal and in the newly created 'DadosAbertos.gov.br'. We use a logit regression model with a binary dependent variable, as described by Hair et al. (2009).

In this class of regression model, the dependent variable y can take only two values. Thus it can represent the occurrence of an event or the choice between two alternatives. This model enables estimation of the probability of fraud y as a function of a vector x of explanatory variables formed by the characteristics of the service, the bidding process, or the supplier.

An objective of the model is to quantify the relationship between the explanatory variables and the probability of fraud in the public procurement system, also based on the CGU and the TCU archives, which enable those auctions in which the winner was punished or investigated to be captured. Another objective is to analyse the marginal effect, in probabilistic terms, of a given explanatory variable on the probability of occurrence of fraud. The dependent variable y takes the values 0 (no punishment or investigation for fraud) or 1 (punishment or investigation for fraud).

In a first step we built a database with information about the winners of the bids and the contracted values extracted from the Purchasing Portal of the federal government. The amount of contracted services in the period covered was around BRL260 billion. This encompassed all types of bidding, which resulted in 557,567 procurement processes.

We screened the data by period, type of bidding, and form of bidding, finding a total of more than BRL120 billion in acquisitions through electronic auctions for which 111,068 auctions were held. As the focus of our research is auctions for contracting services, because these have only one winning bidder per item auctioned, we conducted a screening process. This process resulted in a universe of 54,966 auctions in the electronic auction bidding modality related to contracting services, which we used in our regression analysis with bid values starting at BRL0.01 (one cent).

A simple linear regression of y versus x, which represents a linear probability model, is not appropriate as the error terms are not normally distributed but are binomial and heteroskedastic, and it may still be the case that the calculated conditional probabilities do not belong to the closed range 0 and 1. Therefore we had to work with a specification designed to control the requirements of models with binary dependent variables (Fávero and Belfiore 2017; Hair et al. 2009; Schön 2003).

The two binary choice models—logit and probit—suit the purpose of this research. We chose the logit model because of its simplicity regarding the calculations inherent to the logistic cumulative function and the ease of handling the odds ratio resulting from the model (Campos 2012; Hair et al. 2009; Maddala 1992).

Simple logistic regression model

When the response variable is binary, taking the values 1 and 0, with probabilities π and 1-0, respectively, Y is a *Bernoulli* variable with the parameter $E(Y) = \pi$. The model in its usual form is given by:

$$Y_i = E(Y_i) + \varepsilon_i \tag{1}$$

where:

$$E(Y_i) = \pi_i = \frac{\exp(\beta_0 + \beta_1 X_i)}{1 + \exp(\beta_0 + \beta_1 X_i)} \tag{2}$$

After estimating the logit model, the quality of the results obtained must be analysed based on the following elements:

1) LR (likelihood ratio) test statistic which tests the null hypothesis that explanatory variables together have no effect on y; and
2) The results obtained are only valid if the error terms of the adjusted model, via maximum likelihood, are homoscedastic. If this does not happen, the generated estimators are inconsistent.

Apparent Overbilling Index

From the analysis of the variables in the model, and supported by the literature, we propose an innovative metric for calculating overbilling by suppliers: the ratio between the amount bid and the amount estimated by the bidding agency. We call this the Apparent Overbilling Index (AOI), which consists of the following formula:

$$AOI = \frac{(BV-EV)}{EV} \tag{3}$$

where BV = bidding value and EV = estimated value, both considering the unit price in the auction.

We used Microsoft Excel software and the Stata 17 statistical package for the quantitative analysis.

To perform the logistic regression we prepared the data in an Excel spreadsheet and then inserted it into the Stata software. In developing the process we generated tables, figures, and graphs, as detailed below:

1) Table 3 describes the logistic regression model variables and details clusters, the variables, and their descriptions and classification according to whether they are dependent or independent. We have one dependent variable and five independent variables, divided into two clusters.
2) Figure 2 illustrates the mechanism of the empirical method, showing the dependent variable and its possible relationship with the independent variables.
3) Table 4 presents the descriptive statistics of the variables, with all the variables and their main measures such as number of observations, minimum and maximum values, mean, standard deviation, missing values, and description.

4) Table 5 shows the logistic regression itself, with the regression coefficient (β), the standard error, the Z(Wald), the degrees of leadership (df), the P>|z|, the odds ratio (ODDS RATIO-OR), and the confidence interval.
5) Table 6 shows the omnibus test of the model's coefficients.
6) Table 7 shows the measures of model fit.
7) Table 8 shows the Hosmer and Lemeshow test.
8) Figure 3 shows the receiver operating characteristic (ROC) curve.

## 4.1 Description of variables and empirical model

The description of the variables which enable us to test our hypotheses is presented in Table 3.

Table 3: Description of variables in the logistic regression model

Cluster	Variable	Description	Variable type
Response or dependent variable	V1	Variable to be explained by the model: admitting that the dependent variable y assumes the values 0 or 1 (electronic auction with a supplier sanctioned due to fraud). The probability of observing yt=1 is given by the logit model.	Dependent
Bidding process features	V2	Winning bid value (BRL)	Independent
	V3	Apparent Overbilling Index	Independent
Supplier features	V4	Small enterprise	Independent
	V4(1)	Micro enterprise	Independent
	V4(2)	Large company	Independent

Source: authors' compilation.

Figure 2: Mechanism of the relationship between punished companies and electronic auctions

MECHANISM

y=0 ou y=1(Punished firm)
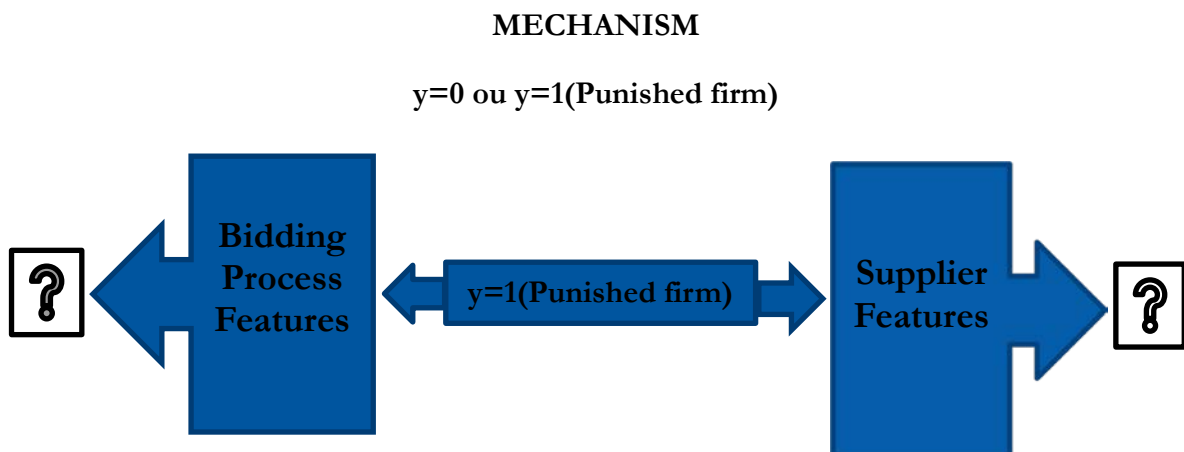
Source: authors, based on Sampaio (2012).

The mechanism shown in Figure 2 helps us to understand how the bidding process and supplier features affect fraud in public procurement. In the regression, the loss function used for the estimation is the maximum likelihood function. The loss function is nothing more than a

mathematical function which evaluates the distance between the values predicted by the model and the observed value, as used by Schön (2003). The idea of any nonlinear model-fitting procedure is always to minimize the loss function, i.e. to make the model as close as possible to the actual values. Furthermore the maximum likelihood function works with the logic of the probability of randomly finding all values for the parameters found in the simulation. We therefore determined the significance of the model in this way. We defined the estimation method after defining the loss function.

In this way we attempted to make the model provide a good solution which minimized the loss function with a minimum of iterations.

5   Results and discussion

Table 4 presents the statistics for the variables under study. As these are categorical variables, 0 or 1, they are described in terms of the occurrence of each category. We present the mean, minimum, maximum, standard deviation, as well as the missing values, i.e. the cases in the table for which there was no information for the variable.

The figures in Table 4 for V1, the response or dependent variable, indicate that punished companies participated in 2,002 biddings out of the 54,966 analysed, which represents 3.64 per cent of the total sample. In this descriptive, there were no missing values.

Still in Table 4, in V2, it shows that the highest contract value was BRL110,299,965, contracted by a call centre company, while the lowest was BRL0.01 contracted by a telephone company (the value refers to a minute of a phone call). The mean contract value was BRL106,755 and no missing values were registered.

For V3, the AOI, the maximum value was 7,119,999, the mean was 135.53, and the minimum was -1, with 8 missing values, which were treated following the 'total mean substitution' technique described by Dodeen (2003), which, in summary, consists in replacing the missing values with the valid mean. After this treatment, there were no missing values.

Table 4: Descriptive statistics of the variables

Cluster	Variable	No.	Min.	Max.	Mean	Std. Dev	Missing	Description
Response or dependent variable	V1	2,002	0	1	.0364225	.1873407	0	Variable to be explained by the model: admitting that the dependent variable y assumes the values 0 or 1 (electronic auction with a supplier sanctioned due to fraud). The probability of observing yt=1 is given by the logit model. There were 2,002 'irregular' auctions.
Bidding Process Features	V2	54,966	0	110,299,965	106,755.1	1,166,245	0	Winning bid value (BRL)
	V3	54,966	-1	7,119,999	135.5365	30,380.7	0	Apparent Overbilling Index
Supplier Features	V4	19,131	0	1	.3480515	.4763568	0	Small enterprise
	V4(1)	17,447	0	1	.3174144	.4654744	0	Micro enterprise
	V4(2)	18,388	0	1	.3345341	.4718316	0	Large company

Source: authors' calculations.

Also in Table 4, in the supplier features cluster (by size), over four years there were 54,966 electronic biddings for the procurement of services in the Brazilian public procurement system. Of these, 17,447 were won by micro enterprises (31.7 per cent), 19,131 by small enterprises (34.8 per cent), and 18,388 by large companies (33.4 per cent), with no record of missing values.

In addition to the general aspects of the model described in Table 4, the specific conditions that led to the results are described below.

The loss function used for the estimation was the maximum likelihood function. The loss function is nothing more than a mathematical function which evaluates how far the values predicted by the model are from the observed value, as used by Schön (2003). The idea of any nonlinear model-fitting procedure is always to minimize the loss function, i.e. to make the model as close as possible to the actual values. Furthermore the maximum likelihood function works with the logic of the probability of randomly finding all the values for the parameters found in the simulation. The significance of the model is then determined in this way.

We defined the estimation method after defining the loss function. In this sense we sought to make the model find a good solution which minimized the loss function with a minimum of iterations.

Table 5 presents the main metrics used in the logistic regressions.

Table 5: Logistic regression

	β	S.E.	Z(Wald)	df	P>|z|	OR	95% C.I. To OR	
							Inf	Sup
V2 (BRL)	2.91e-08	9,13E-09	3.18	1,000	0,001	1,000	1.12e-08	4.70e-08
V3 AOI	**-.6975018**	**.0666384**	**-10.47**	**1,000**	**0,000**	**.4978274**	**-.8281106**	**-.566893**
V4 Small ent.	-	-	-	-	-		-	-
V4(1) micro ent.	-.1327149	.0697935	-1.90	1,000	0,057	.8757148	-.2695077	.004078
V4(2) large company	**.9381185**	**.0561446**	**16.71**	**1,000**	**0,000**	**2.555169**	**.8280771**	**1.04816**
Intercept	3.9345969	.0536476	-73.34	1,000	0,000	.0195536	-4.039743	-3.829448

Source: authors' calculations.

In Table 5 the two variables related to our hypotheses significantly affect the odds ratio of 'being punished'—the dependent variable. A larger value of V3 (AOI) decreases the odds of being among the punished companies—**not supporting and inverting what was expected according to hypothesis H1**. A larger AOI value decreases the odds of being among the punished companies by 0.4978 times. Large companies have an odds ratio of 2.555 (times greater) for being punished.

Table 6: Omnibus test of model coefficients

x^2	df	Sig
6.93e+12	5	0,00

Source: authors' calculations.

The omnibus test in Table 6 tests whether the successive models in the iterative steps of the regression are better than the initial base model of the iterative process. As the P values are highly significant, this indicates that the parameter estimates obtained after the iterative process are much better than an initial model (Fernandes et al. 2021; Larry and Bradley 1991).

Table 7: Model goodness-of-fit measures

-2log likelihood	Cox & Snell R²	Nagelkerke R²
-8596.852	0,012	0,012

Source: authors' calculations.

Again, the likelihood in Table 7 shows a comparison of the final model of the iterative process with the initial raw model: the higher this number, the more expressive is the improvement (Fernandes et al. 2021). We estimated the R^2 using two methods: a more conservative one (Cox and Snell 1968) and a more extensive one (Nagelkerke 1991). The coefficient of determination of the model is 1.2 per cent in both.

Despite presenting a low R², this does not represent a weakness of the model, as it is not a linear regression. According to Hosmer (2000), low R^2 values in logistic regressions are the norm and this presents a problem when reporting their values to those accustomed to seeing linear regression values.

Table 8: Hosmer and Lemeshow test

X²	df	Sig
320.23	8	0,00

Source: authors' calculations.

Finally, we have the Hosmer and Lemeshow test in Table 8. It evaluates fitting the model to the data in terms of prediction (Hosmer 2000). There is good prediction when the statistical significance is greater than 0.05. In this case we do not have a good predictive model, but we have a model that allows us to understand the phenomenon (investigate which variables influence but do not accurately predict the outcome).

Figure 3: Receiver operating characteristic (ROC) curve

Area under ROC curve = 0.6507
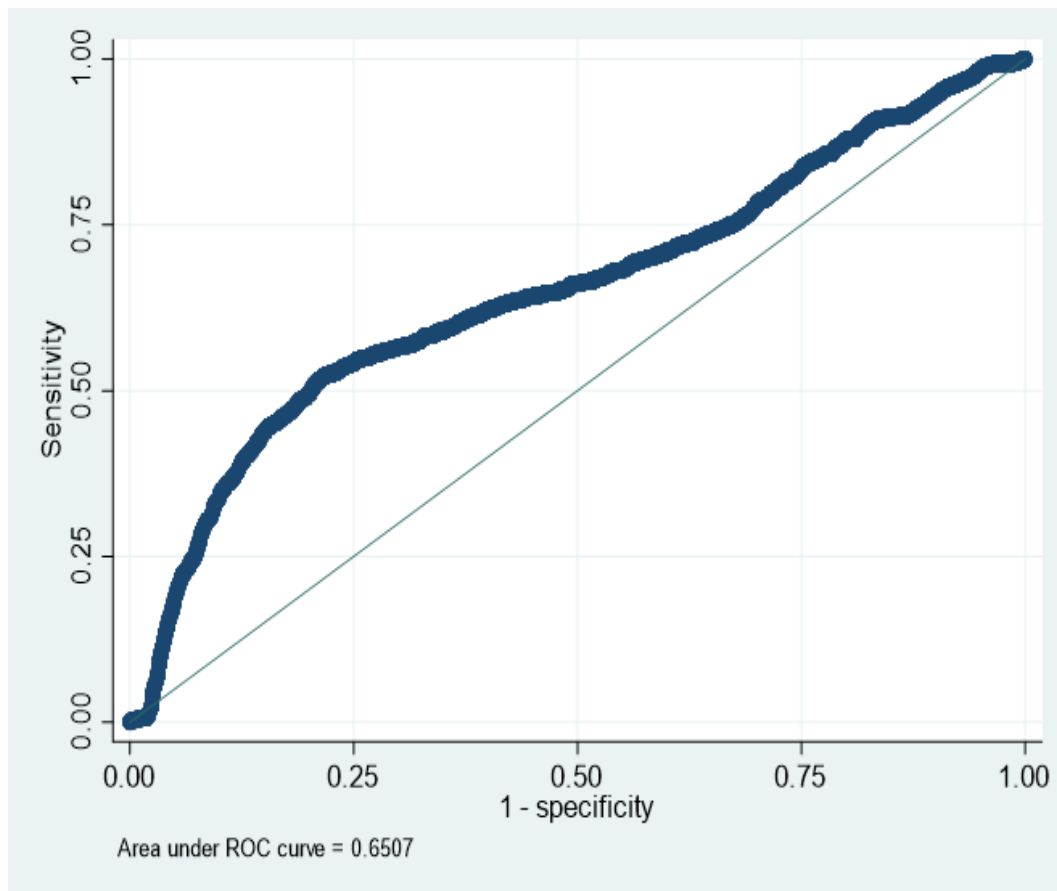
Source: authors' calculations.

Figure 3 shows the receiver operating characteristic (ROC) curve, which emphasizes the sensitivity x specificity of the model. This graph is compatible with logit regression models (Oliveira 2015).

According to Carvalho et al. (2011), this analysis is a graphical representation indicating the performance of a binary classification system from the variation of its discrimination threshold.

According to Witten et al. (2005), ROC curves have true positive rates on the Y axis and false positive rates on the X axis.

From there, the upper-left corner is the ideal point—a false positive rate equal to 0 and a true positive rate equal to 1. Reaching the sweet spot is unusual. However, the larger the area under the curve, the better is the performance of the model.

5.1 Discussion of the results considering the theoretical framework

The results of the empirical investigation show that a larger value of V3 (AOI) decreases the odds of being a punished company—**not supporting and inverting what hypothesis H1 expected**. A larger AOI value decreases the odds of being a punished company by 0.4978 times (less than before).

This result is supported by the studies by Becker (1968), Lengwiler and Wolfstetter (2006), Miroslav et al. (2014), and Rose-Ackerman (1975, 1996, 2014). A possible explanation for this might be that the 'apparent overbilling' is already well observed by the government auditors and is more targeted for verification, so that the punished companies now resort to more elaborate 'tricks', such as price collusion or simulation of competitive values, than inflating the price (Miroslav et al. 2014).

In terms of company size the research findings reveal that being a punished firm is strongly influenced by the winning company being large. The probability of a large company being in the punished group is 2.55 times greater than a small company or 155 per cent greater than SMEs [(2.55-100) x 100]. Thus, **hypothesis H2 is supported.**

This result is compatible with the possibility of collusion by large companies collusion, and is in line with the studies of Albano et al. (2006), Miroslav et al. (2014), and OECD (2016) with regard to the appearance of 'bidding cartels' in procurement, i.e. collusive agreements in bidding processes, as possible forms of anticompetitive practice. It can be understood as corruption (Acemoglu et al. 2004; Becker 1968; Iudícibus et al. 2001; Rose-Ackerman 1975)

According to Lima (2016) a major type of fraud is the collusion of prices among suppliers, i.e. using established companies to frustrate competition in disputes and favouring some participants just to follow the legal procedure.

Our results therefore offer evidence on the factors associated with the occurrence of fraud in the electronic procurement system in Brazil and may contribute to the ongoing debate on this topic in society.

6 Conclusions and implications

This study aimed to investigate which factors are associated with the occurrence of anticompetitive practices in electronic trading systems within the scope of the Brazilian public procurement system. The analysis considered all services contracted from 2014 to 2017.

We used a logit regression model with a binary dependent variable to model the probability of fraud as a function of a vector of explanatory variables composed of the characteristics of the service, the bidding process, and the supplier, thereby quantifying the relationship between the explanatory variables and the likelihood of fraud occurring in the public procurement system.

In responding to the research question, we can therefore state that the company size factor and the AOI are associated with the occurrence of fraud and anticompetitive practices in electronic auctions, and that large companies are more likely to be associated with these occurrences. Bids

with a higher AOI have a lower probability of association with the occurrence of fraud in electronic auctions.

This study contributes to the accumulation of empirical and theoretical knowledge and offers safer bases for governments and society to combat corruption, leading to greater effectiveness and efficiency of public spending. The results also show that even after the introduction of strong anti-corruption legislation in Brazil, fraud still occurs in the most secure type of bidding, the electronic auction.

The study's main limitation is that our proxy for 'occurrence of fraud' is 'has been punished'. However, not all fraudsters always commit fraud (in all the auctions in which they participate). Moreover the evidence for fraud is based on 'punishment', but the efficiency of the 'punishment system' is not taken into account. According to Faria (2004) and Yeung and Azevedo (2012), the Brazilian legal system is still known worldwide for its slowness, inefficiency, and corruption. Another limitation of the paper is the low coefficient of determination (R^2) of the regression, which is a strong indication that the phenomenon can be explained by other variables besides those studied here.

Further studies could explore temporal and sector-based differences, for example by decomposing data analysis by year or decomposing data into clusters, i.e. by sector type (e.g., infrastructure, information and computer technology, health), the sectors with highest contract values.

We also recommend deepening studies based on the economics of corruption of issues which involve endogenous and exogenous relations and the dynamics of the corruption process as contributions to understanding the process.

References

Acemoglu, D., S. Johnson, and J. Robinson (2004). 'Institutions As the Fundamental Cause of Long-run Growth'. NBER Working Paper 10481. Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w10481

Ades, A., and R. Di Tella (1997). The New Economics of Corruption: A Survey and some New Results. *Political Studies,* XLV: 496–515. https://doi.org/10.1111/1467-9248.00093

Albano, G.L., P. Buccirossi, G. Spagnolo, and M. Zanza (2006). 'Preventing Collusion in Procurement'. In N. Dimitri, G. Piga, and G. Spagnolo (eds.), *Handbook of Procurement*. Cambridge: Cambridge University Press.

Almeida, H.F., and L.A. Chacha (2014). 'Dilema do Prisioneiro Iterado e Estratégia Evolucionariamente Estável: Uma Abordagem Econômica'. *Revista de Economia*, 40(1). https://doi.org/10.5380/re.v40i1.32404

Aranha, A.L.M. (2015). 'A rede brasileira de instituições de accountability: um mapa do enfrentamento da corrupção na esfera local'. Doctoral thesis. Belo Horizonte: Universidade Federal de Minas Gerais.

Arief, H.A.A., G.P. Saptawati, and Y.D.W. Asnar (2016). 'Fraud Detection Based on Data Mining on Indonesian E-procurement System (SPSE)'. In 2016 *International Conference on Data and Software Engineering* (ICoDSE). IEEE. https://doi.org/10.1109/ICODSE.2016.7936111

Bajari, P., R. McMillan, and S. Tadelis (2009). 'Auctions Versus Negotiations in Procurement: An Empirical Analysis'. *The Journal of Law, Economics, & Organization*, 25(2): 372–99. https://doi.org/10.1093/jleo/ewn002

Baldomir, R.A., G.C. Van Erven, and C.G. Ralha (2018). 'Brazilian Government Procurements: An Approach to Find Fraud Traces in Companies Relationships'. In *Anais do XV Encontro Nacional de*

Inteligência Artificial e Computacional. Porto Alegre: Sociedade Brasileira de Computação. https://doi.org/10.5753/eniac.2018.4464

Barngetuny, D.C., and G. Kimutai (2015). 'Effects of E-procurement on Supply Chain Management Performance in Elgeyo-Marakwet County'. *International Academic Journal of Procurement and Supply Chain Management*, 1(5): 99–120

Becker, G.S. (1968). 'Crime and Punishment: An Economic Approach'. In N.G. Fielding, A. Clarke, and R. Witt (eds), *The Economic Dimensions of Crime*. London: Palgrave Macmillan. https://doi.org/10.1007/978-1-349-62853-7_2

Brazil Communication Company (2017). 'Government Launches Tool to Improve Price Research in Public Purchases'. Available at http://agenciabrasil.ebc.com.br/geral/noticia/2017-04/governo-lanca-ferramenta-para-aperfeicoar-pesquisa-de-precos-em-compras (accessed October 2017).

CADE (2007). *Guia prático do CADE A defesa da concorrência no Brasil* [*CADE PRACTICAL GUIDE The defense of competition in Brazil*]. Coleção CIEE – Especial (esgotado). 3ª edição revista, ampliada e bilíngüe. São Paulo: CIEE.

CADE (2016). 'Questions on Violations against the Economic Order'. Available at: http://antigo.cade.gov.br/cade_english/servicos/faq-1/questions-on-violations-against-the-economic-order (accessed 17 March 2022).

Campana, M.B. (2018). 'A fraude na modalidade de licitação pregão eletrônico'. *Revista Juris UniToledo*, 3(02).

Campos, F.D.A.O. (2012). 'Three Essays on the Economics of Corruption'. Thesis (PhD) Federal University of Ceará, Postgraduate Program in Economics. Benfica: CAEN, Fortaleza-CE. Available at: https://repositorio.ufc.br/handle/riufc/4948 (accessed in September 2021).

Carneiro, D., P. Veloso, A. Ventura, G. Palumbo, and J. Costa (2020). 'Network Analysis for Fraud Detection in Portuguese Public Procurement'. In Proceedings of International Conference on Intelligent Data Engineering and Automated Learning, Guimaraes, Portugal, 4–6 November. https://doi.org/10.1007/978-3-030-62365-4_37

Carvalho, A.C.P.L.F., K. Faceli, A. Lorena, and J. Gama (2011). *Artificial Intelligence-a Machine Learning Approach*. Rio de Janeiro: LTC.

Chen, J. (2021). 'Understanding Antitrust Laws'. *Investopedia*, 29 May. Available at: https://www.investopedia.com/ask/answers/09/antitrust-law.asp (accessed 17 March 2022).

Colebatch, H.K. (2002). 'Government and Governmentality: Using Multiple Approaches to the Analysis of Government'. *Australian Journal of Political Science*, 37(3): 417–35. https://doi.org/10.1080/1036114021000026346

Congresso em Foco (2017). 'Polícia Federal e CGU combatem fraudes no pregão eletrônico do governo federal'. Available at: https://congressoemfoco.uol.com.br/especial/noticias/policia-federal-e-cgu-combatem-fraudes-no-pregao-eletronico-do-governo-federal/ (accessed 11 February 2019).

Costa, A.P.P., and T.W. Júnior (2012). Fraudes corporativas. *RAE-Revista de Administração de Empresas*, 52(4) : 464–72. https://doi.org/10.1590/S0034-75902012000400008

Cox, D.R., and E.J. Snell (1968). 'A General Definition of Residuals'. *Journal of the Royal Statistical Society: Series B (Methodological)*, 30(2): 248–65.

Decarolis, F., and C. Giorgiantonio (2020). 'Corruption Red Flags in Public Procurement: New Evidence from Italian Calls for Tenders'. SSRN. https://doi.org/10.2139/ssrn.3744084

de Pinho, J.A.G. (2008). 'Investigando portais de governo eletrônico de Estados no Brasil: muita tecnologia, pouca democracia'. *Revista de Administração Pública*, 42(3). https://doi.org/10.1590/S0034-76122008000300003

De Rond, M., and R.-A. Thietart (2007). 'Choice, Chance, and Inevitability in Strategy'. *Strategic Management Journal*, 28(5): 535–51.

De Souza, F.P., and F. da Rocha Louzada (2020). 'Detectando conluio em compras governamentais: Uma abordagem utilizando Red Flags e a Teoria Dempster-Shafer'. *Revista da CGU*, 12(21): 80–99.

Dodeen, H.M. (2003). 'Effectiveness of Valid Mean Substitution in Treating Missing Data in Attitude Assessment'. *Assessment & Evaluation in Higher Education*, 28(5): 505–13. https://doi.org/10.1080/02602930301674

Domingos, S.L., R.N. Carvalho, R.S., Carvalho, and G.N. Ramos (2016). 'Identifying IT Purchases Anomalies in the Brazilian Government Procurement System Using Deep Learning'. In 15th IEEE International Conference on Machine Learning and Applications (ICMLA). https://doi.org/10.1109/ICMLA.2016.0129

Donahue, J.D. (1989). *The Privatization Decision: Public Ends, Private Means*. New York, NY: Basic Books.

Faria, J.E. (2004). 'O sistema brasileiro de Justiça: experiência recente e futuros desafios'. *Estudos avançados*, 18(51): 103–25. https://doi.org/10.1590/S0103-40142004000200006

Fávero, L.P., and P. Belfiore (2017). *Handbook of Data Analysis: Statistics and Multivariate Modeling with Excel®, SPSS® and Stata®*. Rio de Janeiro: Elsevier.

Fazekas, M., and G. Kocsis (2020). 'Uncovering High-level Corruption: Cross-national Objective Corruption Risk Indicators Using Public Procurement Data'. *British Journal of Political Science*, 50(1): 155–64. https://doi.org/10.1017/S0007123417000461

Fazekas, M., Tóth, I.J., and L.P. King (2013). 'Corruption Manual for Beginners: "Corruption Techniques" in Public Procurement with Examples from Hungary'. Corruption Research Center Budapest Working Paper CRCB-WP/2013, 1. Available at: http://hdl.handle.net/10419/108320 (accessed March 2021).

Fazekas, M., I.J. Tóth, and L.P. King (2016). 'An Objective Corruption Risk Index Using Public Procurement Data'. *European Journal on Criminal Policy and Research*, 22(3): 369–97. https://doi.org/10.1007/s10610-016-9308-z

Federative Republic of Brazil (2008). *Combate a Cartéis em Licitações: A Practical Guide for Tenderers and Bid Committee Members*. Brasília: MJ/SDE/Departamento de Proteção e Defesa Econômica.

Fernandes, A.A.T., D.B. F. Filho, E.C. da Rocha, and W. Da.Silva Nascimento (2021). 'Read This Paper If You Want to Learn Logistic Regression'. *Revista de Sociologia e Politica*, 28(74). https://doi.org/10.1590/1678-987320287406en

Ferwerda, J., I. Deleanu, and B. Unger (2017). 'Corruption in Public Procurement: Finding the Right Indicators'. *European Journal on Criminal Policy and Research*, 23(2): 245–67.

Gallego, J., G. Rivero, and J. Martínez (2021). 'Preventing Rather Than Punishing: An Early Warning Model of Malfeasance in Public Procurement'. *International Journal of Forecasting*, 37(1): 360–77. https://doi.org/10.1016/j.ijforecast.2020.06.006

Gilauri, N. (2017). 'Fighting Corruption'. In N. Gilauri (ed.), *Practical Economics*. Cham: Palgrave Macmillan. https://doi.org/10.1007/978-3-319-45769-7

Gray, D.E. (2012). Pesquisando e usando bibliografia. In D.E. Gray (ed.), *Pesquisa no Mundo Real*. Tradução: Roberto Calado Costa. 2 ed. Porto Alegre.

Hair, J.F., W.C. Black, B.J. Babin, R.E. Anderson, and R.L. Tatham (2009). *Análise multivariada de dados*. Porto Alegre: Bookman.

Hanák, T. (2018). 'Electronic Reverse Auctions in Public Sector Construction Procurement: Case Study of Czech Buyers and Suppliers'. *TEM Journal*, 7(1): 41–52.

Hay, G.A. (1985). 'Anti-Trust and Economic Theory: Some Observations from the US Experience'. Cornell Law Faculty Publications 1152. Ithaca, NY: Cornell Law School.

Heath, J., and W. Norman (2004). 'Stakeholder Theory, Corporate Governance, and Public Management: What Can the History of State-run Enterprises Teach Us in the Post-Enron Era?'. *Journal of Business Ethics*, 53(3) 247–65. https://doi.org/10.1023/B:BUSI.0000039418.75103.ed

Hosmer, D.W. (2000). *Applied Logistic Regression, Second Edition*. New York, NY: John Wiley & Sons.

Howard, M., R.T. Vidgen, P. Powell, and A. Graves (2002). 'Are Hubs the Centre of Things? E-procurement in the Automotive Industry'. In proceedings of ECIS June 6–8, Gdansk, Poland. Available at: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.109.7366&rep=rep1&type=pdf (accessed September 2021).

Huber, B., E. Sweeney, and A. Smyth (2004). 'Electronic Purchasing Consortia: A Procurement Direction for the Future?'. Working Paper. In The Purchasing Function: Walking a Tightrope, Proceedings of the 13th International Purchasing and Supply Education and Research. Association (IPSERA) Conference, Catania, Italy.

Iudícibus, S.D., J.C. Marion, E. Pereira, and V. Slomski (2001). *Dicionário de termos de contabilidade*. 2. ed. São Paulo: Atlas.

Jamal, K., P.E. Johnson, and R.G. Berryman (1995). 'La détection des effets de mise en scène dans les états financiers'. *Contemporary Accounting Research*, 12(1): 107–30. https://doi.org/10.1111/j.1911-3846.1995.tb00483.x

Köbis, N., C. Starke, and I. Rahwan (2021). 'Artificial Intelligence as an Anti-Corruption Tool (AI-ACT): Potentials and Pitfalls for Top-down and Bottom-up Approaches'. arXiv preprint arXiv:2102.11567.

Köbis, N.C., J.W. van Prooijen, F. Righetti, and P.A. Van Lange (2017). 'The Road to Bribery and Corruption: Slippery Slope or Steep Cliff?'. *Psychological Science*, 28(3): 297–06. https://doi.org/10.1177/0956797616682026

Larry G.B., and E.L. Bradley (1991). 'An Omnibus Test for Comparing Two Measuring Devices'. *Journal of Quality Technology*, 23(1): 12–16. https://doi.org/10.1080/00224065.1991.11979278

Lee, J.H., Y. Iwasa, U. Dieckmann, and K. Sigmund (2019). 'Social Evolution Leads to Persistent Corruption'. *Proceedings of the National Academy of Sciences*, 116(27): 13276–81. https://doi.org/10.1073/pnas.1900078116

Lengwiler, Y., and E. Wolfstetter (2006). 'Corruption in Procurement Auctions'. In N. Dimitri, G. Piga, and G. Spagnolo (eds), *Handbook of Procurement*. Cambridge: Cambridge University Press. https://doi.org/10.2139/ssrn.874705

Lima, W.R. (2016). 'Combate à fraude nos pregões eletrônicos'. JUSBRASIL. Available at: https://welderrodrigues75.jusbrasil.com.br/artigos/305111777/combate-a-fraude-nos-pregoes-eletronicos (accessed March 2021).

Maddala, G.S. (1992). *Introduction to Econometrics*. Second Edition. New York, NY: Macmillan Publishing Company.

Mencía, E.L., S. Holthausen, A. Schulz, and F. Janssen (2013). 'Using Data Mining on Linked Open Data for Analyzing E-procurement Information'. In Proceedings of the first DMoLD: Data Mining on Linked Data Workshop at ECML/PKDD.

Miles, R.E., Jr. (1978). 'The Origin and Meaning of Miles' Law'. *Public Administration Review*, 38(5): 399–403. https://doi.org/10.2307/975497

Miranzo Diaz, J. (2017). 'A Taxonomy of Corruption in EU Public Procurement'. *European Procurement & Public Private Partnership Law Revive.*, 12(4): 383–95. https://doi.org/10.21552/epppl/2017/4/5

Miroslav, M., M. Miloš, S. Velimir, D. Božo, and L. Đorđe (2014). 'Semantic Technologies on the Mission: Preventing Corruption in Public Procurement'. *Computers in Industry*, 65(5): 878–90. https://doi.org/10.1016/j.compind.2014.02.003

Modrušan, N., L. Mršić, and K. Rabuzin (2021). 'Intelligent Public Procurement Monitoring System Powered by Text Mining and Balanced Indicators'. In S. Hammoudi, C. Quix, J. Bernardino (eds), *Data Management Technologies and Applications*. DATA 2020. *Communications in Computer and Information Science*, 1446. Cham: Springer. https://doi.org/10.1007/978-3-030-83014-4_6

Modrušan, N., L. Mršić, and K. Rabuzin (2020). 'Intelligent Public Procurement Monitoring System Powered by Text Mining and Balanced Indicators'. In International Conference on Data Management Technologies and Applications. Cham: Springer.

Modrušan, N., K. Rabuzin, and L. Mršić (2020). 'Improving Public Sector Efficiency using Advanced Text Mining in the Procurement Process'. In Proceedings of the 9th International Conference on Data Science, Technology and Applications – DATA: 200–206. https://doi.org/10.5220/0009823102000206

Nagelkerke, N. J. (1991). 'A Note on a General Definition of the Coefficient of Determination'. *Biometrika*, 78(3), 691–92. https://doi.org/10.1093/biomet/78.3.691

Neupane, A., J. Soar, and K. Vaidya (2012a). 'The Potential of e-Procurement Technology for Reducing Corruption'. *International Journal of Information Technology and Management*, 11(4): 273–87. https://doi.org/10.1504/IJITM.2012.049997

Neupane, A., J. Soar, and K. Vaidya (2012b) 'Evaluating the Anti-Corruption Capabilities of Public E-Procurement in a Developing Country'. *The Electronic Journal of Information Systems in Developing Countries*, 55(1): 1–17. https://doi.org/10.1002/j.1681-4835.2012.tb00390.x

Neupane, A., J. Soar, and K. Vaidya (2014). 'Anti-corruption Capabilities of Public E-procurement Technologies: Principal-Agent Theory'. In K.J. Bwalya (ed.), *Technology Development and Platform Enhancements for Successful Global E-Government Design*. Hershey, PA: IGI. https://doi.org/10.4018/978-1-4666-4900-2.ch010

Nollet, V., T. Marescaux, P. Avasare, D. Verkest, and J.-Y. Mignolet (2005). 'Centralized Run-time Resource Management in a Network-on-chip Containing Reconfigurable Hardware Tiles'. In Proceedings of Design, Automation and Test in Europe Conference, 7–11 March, Munich. IEEE. Available at: https://ieeexplore.ieee.org/document/1395562 (accessed September 2021).

OECD (2008). *Fighting Bribery in Public Procurement in Asia-Pacific*. Available at: https://www.oecd.org/site/adboecdanti-corruptioninitiative/40838411.pdf (accessed 17 February 2019). https://doi.org/10.1787/9789264046955-en

OECD (2009). *Guidelines for Fighting Bid Rigging in Public Procurement: Helping Governments to Obtain Best Value for Money*. Available at: https://www.oecd.org/competition/guidelinesforfightingbidrigginginpublicprocurement.htm (accessed 17 March 2022).

OECD (2016). *Fighting Bid Rigging in Public Procurement: Report on Implementing the OECD Recommendation*. Available at: https://www.oecd.org/daf/competition/Fighting-bid-rigging-in-public-procurement-2016-implementation-report.pdf (accessed 12 June 2019).

OECD (2018). *Recomendação do Conselho da OCDE sobre Integridade Pública*. Available at: https://www.oecd.org/gov/ethics/integrity-recommendation-brazilian-portuguese.pdf (accessed 11 June 2019).

OECD (n.d.). *Public Procurement Toolbox*. Available at: https://www.oecd.org/governance/procurement/toolbox/about/terminology/ (accessed 17 March 2022).

OLAF (2017). 'Fraud in Public Procurement: A Collection of Red Flags and Best Practices'. Ref. Ares (2017) 6254403. Brussels: European Anti-Fraud Office.

De Oliveira, E.L.S. (2015). 'An Investigation of Aspects of Topic Classification for Short Texts'. Master's Dissertation. Paraíba: Universidade Federal da Paraíba. Available at: https://repositorio.ufpb.br/jspui/bitstream/tede/7842/2/arquivototal.pdf (accessed September 2021).

Rabuzin, K., and N. Modrušan (2019). 'Prediction of Public Procurement Corruption Indices Using Machine Learning Methods'. In Proceedings of the 11th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management (IC3K 2019. https://doi.org/10.5220/0008353603330340

Ralha, C.G., and C.V.S. Silva (2012). 'A Multi-agent Data Mining System for Cartel Detection in Brazilian Government Procurement'. *Expert Systems with Applications*, 39(14): 11642–56. https://doi.org/10.1016/j.eswa.2012.04.037

Rebouças, R.R., H.A. do Prado, E. Ferneda, and R. Balaniuk (2017). 'Detecção de figurantes em pregões eletrônicos do governo federal brasileiro'. *Informação & Tecnologia*, 2(2): 5–21.

Rose-Ackerman, S. (1975). 'The Economics of Corruption'. *Journal of Public Economics*, 4(2): 187–203. https://doi.org/10.1016/0047-2727(75)90017-1

Rose-Ackerman, S. (1996). 'The Political Economy of Corruption: Causes and Consequences'. Viewpoint Note 74. Washington, DC: World Bank.

Rose-Ackerman, S. (2014). 'Corruption and Conflicts of Interest'. In J.-B. Auby, E. Breen, and T. Perroud (eds), *Corruption and Conflicts of Interest: A Comparative Law Approach*. Cheltenham: Edward Elgar Publishing.

Sacramento, A.R.S., and J.A.G. de Pinho (2018). 'Combate à Corrupção no Brasil: Identificando Entraves à Luz da Versão Revisitada da Teoria da Modernização'. *Revista Interdisciplinar de Gestão Social*, 7(1).

Sales, L. (2013). 'Risk Prevention of Public Procurement in the Brazilian Government Using Credit Scoring'. OBEGEF Working Paper on Fraud and Corruption. Porto: Observatório de Economia e Gestão de Fraude.

Sales, L.J., and R.N. Carvalho (2016). 'Measuring the Risk of Public Contracts Using Bayesian Classifiers'. *BMA@ UAI*, 7–13.

Sampaio, A.H. (2012). 'A Study on the Participation of Micro and Small Companies in Electronic Auctions Held at FIOCRUZ/BA'. Master's Dissertation. Salvador: School of Management, Federal University of Bahia, Brazil.

Sampaio, A.H., P.S. Figueiredo, and E. Loiola (2022). 'Public Procurement in Brazil: Evidence of Frauds Using the Newcomb-Benford Law'. *Journal of Public Management & Citizenship*, 27(86).

Schön, T. (2003). 'On Computational Methods for Nonlinear Estimation'. Linköping Studies in Science and Technology Thesis 1047. Linköping: Linköping University. Available at: http://users.isy.liu.se/rt/schon/Publications/Schon2003.pdf (accessed March 2021).

Setyadiharja, R., S. Budiman, Z.A. Karim, R.A., Matridi, and A. Nurmandi (2014). 'E-procurement System Technology: an Analysis in Electronic Procurement Service Unit (LPSE) of Kepulauan Riau Province'. *The Asian Journal of Technology Management*, 7(2): 93.

Silva, A.A., and R.T. Ferreira (2007). 'Pregões eletrônicos realizados pela prefeitura municipal de fortaleza em 2006: um ensaio econométrico. Fortaleza: Prêmio Sefin de Finanças Municipais'.

Søreide, T. (2002). 'Corruption in Public Procurement : Causes, Consequences and Cures'. CMI Report 2002: 1. Bergen: Chr. Michelsen Institute.

Sun, T., and L.J. Sales (2018). 'Predicting Public Procurement Irregularity: An Application of Neural Networks'. *Journal of Emerging Technologies in Accounting*, 15(1): 141–54. https://doi.org/10.2308/jeta-52086

Tas, B.K.O. (2017). 'Collusion Detection in Public Procurement with Limited Information'. Economic Research Forum Working Paper 1127. Dokki, Giza: ERF.

TCU (Tribunal de Contas da União) (2018). *Referencial de Combate à Fraude e Corrupção: aplicável a órgãos e entidades da Administração Pública*. Brasília: Secretaria de Métodos e Suporte ao Controle Externo.

Teixeira, H.J., L.P.C. Prado Filho and S.M. Salomão (2016). 'A experiência dos estados brasileiros com o pregão: avanços, limitações e perspectivas'. In Proceedings of IX Congresso CONSAD de Gestão Pública, 8–10 June, Brasília, DF (Vol. 9).

Telesintese (2015). 'TCU constata fraude de empresas no pregão eletrônico'. [Online]. 22 April. Available at: http://www.telesintese.com.br/tcu-constata-fraude-de-empresas-pregao-eletronico (accessed 11 February 2019).

Tóth, I.J., and M. Hajdu (2017). 'Intensity of Competition, Corruption Risks and Price Distortion in Hungarian Public Procurement: 2009–2016'. Working Paper CRCB-WP/2017:2. Budapest: CRCB.

Transparency International (2017). *Corruption Perceptions Index 2016*. Available at: https://www.transparency.org/news/feature/corruption_perceptions_index_2016 (accessed 2 November 2017).

Transparency International (2018). 'Website Homepage'. Available at: https://www.transparency.org (accessed April 2019).

Transparency International (2021). *Corruption Perception Index 2020*. Available at: https://www.transparency.org/en/cpi/2020 (accessed September 2021).

UN (2015). 'Transforming Our World: The 2030 Agenda for Sustainable Development'. Resolution Adopted by the United Nations General Assembly on 2015 September. New York, NY: United Nations.

UNCAC (2004). The United Nations Convention Against Corruption (UNCAC) Resolution Adopted by the United Nations General Assembly at United Nations Office on Drugs and Crime on 31 October 2003. New York, NY: United Nations. Available at: https://www.unodc.org/documents/treaties/UNCAC/Publications/Convention/08-50026_E.pdf (accessed September 2021).

Vachris, M.A. (1996). 'Federal Antitrust Enforcement: A Principal-Agent Perspective'. *Public Choice*, 88(3): 223–38. https://doi.org/10.1007/BF00153231

Van Erven, G.C., R.N. Carvalho, M.T. de Holanda, and C. Ralha (2017). 'Graph Database: A Case Study for Detecting Fraud in Acquisition of Brazilian Government'. In Proceedings of 12th Iberian Conference on Information Systems and Technologies (CISTI) 2017, 21 June, Lisbon. https://doi.org/10.23919/CISTI.2017.7975974

Velasco, R.B., I. Carpanese, R. Interian, O.C. Paulo Neto, and C.C. Ribeiro. (2021). 'A Decision Support System for Fraud Detection in Public Procurement'. *International Transactions in Operational Research*, 28(1): 27–47. https://doi.org/10.1111/itor.12811

Wang, Y. (2016). 'Detecting Fraud in Public Procurement'. Doctoral Dissertation. Stony Brook, NY: State University of New York at Stony Brook.

Wensink, W., and J.M. de Vet (2013). *Identifying and Reducing Corruption in Public Procurement in the EU: Development of a Methodology to Estimate the Direct Costs of Corruption and Other Elements for an EU-evaluation Mechanism in the Area of Anti-corruption*. Brussels: PWC and Ecorys.

Witten, I.H., E. Frank, M.A. Hall, C.J. Pal (2005). 'Data Mining: Practical Machine Learning Tools and Techniques'. Amsterdam: Elsevier.

Yeung, L.L.-T., and P.F. de Azevedo (2012). 'Além dos "achismos" e das evidências anedóticas: medindo a eficiência dos tribunais brasileiros'. *Economia Aplicada*, 16: 643–63. https://doi.org/10.1590/S1413-80502012000400005