ASYMMETRIC INFORMATION IN OIL AND GAS LEASE AUCTIONS WITH A NATIONAL COMPANY

Rafael Matoso
Petrobras
rafael.matoso@petrobras.com.br

Marcelo Rezende
Federal Reserve Board
marcelo.rezende@frb.gov

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Abstract

This paper analyzes the bidding behavior in oil and gas tract auctions in Brazil, where the main winner was Petrobras, a national company which was until recently a monopolist. We test predictions based on the theory of common-value, first-price, sealed-bid auctions with asymmetric information. The evidence indicates that Petrobras was better informed about the tracts' values than other bidders. We show that they bid less frequently than Petrobras for tracts being reoffered after receiving no bids in previous auctions and also find evidence that this firm was constrained in the number of auctions in which it could participate.

1. Introduction

Information asymmetries determine how bidders behave in auctions where they differ in their private information about the common value of the item for sale. Informed and uninformed buyers bid strategically considering the information available to each of them and the optimal bidding strategies they expect from their competitors. The theoretical predictions about bidding behavior and auction results in these settings have found strong support from data from many auctions, including timber rights, government securities, and oil and gas tracts.

Predictions from auction theory, however, depend heavily on the characteristics of each specific market. The rules of the auction and the characteristics of the economic environment determine how bidders behave in equilibrium, and thus the predictions for one auction market do not necessarily apply to other ones (Porter, 1995). In order to evaluate if these theoretical results hold more generally, they must be tested in different markets.

In this paper we test predictions from one of the most important models of auction theory with asymmetric information using new data from oil and gas tract auctions in Brazil. The predictions are based on the noncooperative first-price, sealed bid model with asymmetric information studied by Wilson (1967), Weverbergh (1979), Engelbrecht-Wiggans, Milgrom and Weber (1983), Hendricks and Porter (1988) and Dubra (2006). In this model, one bidder is assumed to be better informed about tract value than its competitors, and we assume in our setting that such position is held by Petrobras, the Brazilian national oil company, which was a monopolist for more than 40 years, currently leads the national market in reserves and production and was the main winner in these auctions. Based on this assumption, we use the model to predict how Petrobras and its competitors should bid in equilibrium.

We test the predictions on the 3,571 auctions for oil and gas tracts conducted in ten annual rounds from 1999 to 2008.[1] These auctions have two characteristics that allow us to test for asymmetric information. First, they have a natural candidate for a bidder with superior

[1] In this paper we use the word "round" to refer to the annual event where tracts were auctioned. Because we study sealed bid auctions, its meaning should not be confused with a turn within an auction where participants can revise their bids, such as in English auctions.

information, namely, Petrobras. Second, many tracts were offered repeatedly: 2,768 out of the 3,571 auctions did not receive any bids and in many of these cases the respective tract was offered again in a future year. Thus, we can study how Petrobras and its competitors bid depending on whether a tract had already been offered in the past and did not attract any bids.[2]

We show that the data support the model's predictions about bidding behavior, including one that explores these particular characteristics of the data. We start from the observation that if Petrobras held superior information that contained any knowledge its competitors might have, then any information that the latter might have revealed through their bids in previous auctions should not affect how Petrobras bid in future auctions for the same tract. On the other hand, Petrobras's bid in an auction should have affected its competitors' bids in future auctions for the same tract because the former's bid contained some of its private information about the tract's value that should have caused its competitors to adjust their estimates. Because these repeated tracts had been offered in a past round, received no bids and were offered again later, this reasoning predicts that Petrobras should have valued tracts that had been offered before relatively more than its competitors. Bidders' participation decisions support our prediction about how bids relate to whether a tract had been offered before. For both onshore and offshore tracts, the ratio between auctions for tracts that were never offered that received bids from Petrobras and from its competitors is lower than for tracts that had been offered before, which indicates that Petrobras valued tracts that had been offered before as opposed to tracts that had never been offered relatively more than its competitors.

We also find evidence that supports a prediction that relates bids to tracts' profitability. The model predicts that if Petrobras had private information about tracts' profitability, then its bids should have been highly correlated with it, while its competitors' should not. To measure profitability, we use a variable that indicates whether the winner already found hydrocarbons in the tract. This variable indicates whether a tract is profitable because winners can only

[2] Porter (1995) analyzes the outer continental shelf oil and gas tract auctions, in which the government held the right to reject bids above reservation prices if it considered them too low. He argues that there was a long period between rejections and resale and a low fraction of tracts being reoffered, which might be inconsistent with revenue maximization.

produce oil or gas after notifying the regulator within a limited time frame. Thus, notification of hydrocarbons should be positively correlated with Petrobras's valuation of tracts and orthogonal to its competitors'. Indeed, Petrobras reported that it found hydrocarbons in 95 out of the 403 tracts that it won, which is almost 50 percent higher than the same figure for its competitors, equal to 63 out of 400. Moreover, the ratio between Petrobras's average winning bid for tracts where hydrocarbons were eventually detected and the average of all its winning bids is larger than the ratio for its competitors.

The data however do not support all the predictions of the model, suggesting that at least one of its assumptions is not valid in the market we study. The number of bids and wins by Petrobras either fell short or barely satisfied their predicted minimum values, which we argue corroborates some evidence that Petrobras and its competitors were constrained in their capacity to bid and explore a large number of tracts, thereby violating the assumption of the model that bidders do not face budget constraints. In general, however, the data adhere to the predictions.

Our paper is closely related to the empirical literature on private information in oil and gas tract auctions (Hendricks and Porter, 1988; Hendricks, Porter and Boudreau, 1987; Hendricks, Porter and Tan, 1993; Hendricks, Porter and Wilson, 1994; Li, Perrigne and Vuong, 2000; Porter, 1995). Hendricks and Porter (1988) show that the bidding behavior observed in the U.S. outer continental shelf (OCS) oil and gas lease sales data conform with predictions from the theoretical model discussed above, which assumes that owners of tracts that neighbored those being auctioned were better informed about their values than non-neighbor firms. We adapt their empirical strategy to test predictions from this theoretical model in our setting. Our work contributes to this literature because despite the fact that most research on how information asymmetry impacts bids has been based on OCS data, this market constitutes an exception rather than the rule in terms of size and ownership. The 13 largest oil companies in the world by size of reserves are state-owned, and together they hold around 90 percent of the world's oil and gas accumulations (Economist, 2006; Oil and Gas Journal, 2010). Because we study oil and gas tract auctions with a national company, we help to understand how pervasive information asymmetries are in these auctions and thus how general the model we test here is.

Oil and gas lease auctions in Brazil have been intensively studied recently (Brasil, Postali and Madeira, 2008; Brasil and Postali, 2010; Matoso, 2009; Perez, 2010; Rodriguez, Colela Jr. and Suslick, 2008). Among these papers, the study that is closest to ours is that of Brasil and Postali (2010), who estimate information rents in these auctions with an independent private values framework. We differ from them by using a model based on the theory of common value auctions and by using data on proxies for tracts' values and on whether these tracts had been offered before to account for private information.

Our paper also contributes to a literature that investigates whether bidders learn from each other. Hortaçsu and Sareen (2005) and Hortaçsu and Kastl (2010) show that Canadian Treasury securities dealers learn about market demand based on bids submitted by their customers through them and bid based on this private information. Athey and Levin (2001) also present evidence from timber auctions consistent with private information being revealed during oral auctions. In our paper we present evidence that bidders learn from others based on bids for reoffered items.

The paper is organized as follows. Section 2 discusses oil and gas exploration in Brazil and the auctions' rules. Section 3 describes the data. Section 4 discusses the predictions from auction theory that we test against the data. Section 5 describes our empirical method and presents the results. Section 6 concludes the paper.

2. Oil and Gas Exploration in Brazil and the ANP Auctions

2.1 Background

Until the mid-nineties, Petrobras, a national company founded in 1953 and controlled by the federal government, held monopoly rights to explore and produce oil and natural gas in Brazil.[3] In 1997, the Brazilian Congress approved the Petroleum Law, thereby establishing a new regulatory framework for this activity in Brazil, opening it to private domestic and foreign firms and creating the National Petroleum Agency (ANP), the federal agency responsible for regulating and overseeing it.[4] Since then, the ANP has auctioned rights to explore and produce oil and natural gas in geographic tracts in ten annual rounds from 1999 to 2008. A total of 2,025 tracts were offered in 3,571 auctions, but only 803 of these auctions received at least one bid.

In 1998, before the first round, the ANP and Petrobras performed what has become known as the Round Zero. The two parties signed 397 contracts whereby the latter obtained leases for the tracts it was already engaged in exploration (115 tracts), development (51 fields) and production (231 fields) of oil or gas when the Petroleum Law was enacted. Sixty-two other fields, which had already produced oil and natural gas or which were under development, were not retained by Petrobras, mainly because these were inactive fields with little hydrocarbon deposits, and thus were returned to the ANP. The total area retained by Petrobras was more than 450 thousand square kilometers, which is large compared to the 7.5 million square kilometers the ANP considers to have potential for exploratory activity in Brazil. Because of the large area where it operated and where it had already explored and due to many years of exclusive experience in Brazilian territory before the ANP auctions, Petrobras was better informed about the value of the tracts offered.

The Petroleum Law, however, restricted the informational advantage that Petrobras had in these auctions. It mandated that this firm transfer to the ANP all data it had acquired about Brazilian sedimentary basins, as well as about research, exploration and production activities

[3] Petrobras's monopoly in exploration and production was interrupted between 1975 and 1988 when private companies were allowed to sign risk contracts with the government. These contracts were a response to the 1973 oil crisis and rewarded firms in case they found and produced hydrocarbons. The list of firms that signed these contracts includes Shell, Exxon, Texaco, BP, among other foreign and domestic ones. New contracts however were prohibited in 1988 when a new Constitution was adopted in Brazil (Lucchesi, 1998).

[4] See Law 9478 of August 6, 1997, known as the Petroleum Law, and the Constitutional Amendment 9 of November 9, 1995. The acronym ANP refer to *Agência Nacional do Petróleo* in Portuguese. The Law 11.097 of January 13, 2005 changed this name to National Petroleum, Natural Gas and Biofuels Agency, or *Agência Nacional do Petróleo, Gás Natural e Biocombustíveis* in Portuguese.

carried out as a monopolist until the date the law was enacted, in 1997, before the first round of auctions. These data were included in the data package that bidders could acquire from the ANP before the auctions, thereby alleviating information asymmetries among bidders. However, Petrobras most likely still benefited from new data that it acquired in its activities after that, from soft information that it was not able to transfer to the ANP, and from organizational and human capital accumulated over those many years. Indeed, some anecdotal evidence indicates that this was actually the case.

The idea that Petrobras acquired knowledge that could be used in oil tract auctions is illustrated by the history of OGX, a new private domestic oil and gas company. OGX was created in 2007 and hired top managers from Petrobras for its CEO and COO positions, among others. According to OGX, its team was responsible for "more than 9 billion boe and 50 fields discovered in the last 6 years" (OGX Petróleo e Gás, 2011) while working for Petrobras.[5] In that very year, OGX won 21 tracts, second only to Petrobras in number of wins. Its participation in the auctions was considered a success, which was attributed by a major newspaper largely to knowledge of its staff: "What guaranteed the choice of goods tracts was exactly the experience of its directors" (O Estado de S. Paulo, 2010).

2.2 Auction Rules

The tracts were leased via first-price, sealed bid auctions. In order to participate in each annual round of auctions, a firm had to comply with certain minimum technical, financial and legal requirements and pay a participation fee which granted it access to seismic and geological data from the tracts offered. Moreover, in order to participate in each auction, each competitor needed the minimum technical qualification demanded by the ANP for the respective tract. Tracts were divided in three categories of minimum qualification required: A, B and C, where A-qualification tracts were the most demanding and C tracts were the least demanding. Offshore tracts required either A or B qualification, while onshore tracts required either B or C

[5] Boe is the acronym for barrels of oil equivalent.

qualification only. In order to satisfy these requirements, firms could organize themselves in consortiums, where the technical qualification of the joint venture was equal to the qualification of the member firm indicated as the operator. Besides Petrobras and OGX, firms that participated in these auctions included large multinational companies, such as Exxon, Chevron, Shell and BP, and smaller domestic companies.

In every annual round of auctions the bidders submitted sealed envelopes containing their bids for the tracts in which they were interested. From the first to the fourth round – 1999 to 2002 - bidders submitted envelopes after the winner of the previous auction was announced. From the fifth round (2005) on, auctions were divided into groups and bidders had to submit the envelopes for every auction within a group simultaneously. After that, all the bids for each tract within a group were revealed, the respective winners announced, and this process was repeated for the next group.

The definitions and rules in these auctions were as follows. A bid was a combination of a bonus, a percentage of domestic content of inputs, and a minimum exploratory program. The bonus was the price in local currency (real, R$) which the bidder promised to pay to the ANP if it won the auction. The domestic content of inputs was the fraction of goods and services that the firm promised to acquire from domestic suppliers.[6] The bidder had to submit separate fractions for the inputs to be acquired for the exploration and the development of production phases. A minimum exploratory program detailed the minimum area and volume of seismic studies and the minimum number and depth of exploratory wells that the bidder promised to drill in case it won the tract, as well as the financial guarantees it had to present to assure the regulator that it was capable of conducting these studies. These items were then combined into a grade for the minimum exploratory program. The bonus, the national content of inputs, and the minimum exploratory program were all constrained by minimum values.

The bonus, the national content in exploration and in development and the minimum exploratory program were aggregated into a score and the bidder with the highest score won

[6] These inputs were weighted differently depending on whether they were expected to be used in the exploratory or production period of activity.

the auction. This score assigned weights to each of these four items. These weights were constant within each round but varied over time, as shown in Table 1. The bonus' weight, for example, varied between 30 and 85 percent and the minimum exploratory program had no weight until 2003. The score of each bidder in each item was given by the ratio between its bid and the maximum bid for the tract. For example, for tracts auctioned between 2005 and 2008 the bonus' weight was equal to 40 percent. If a bidder then offered a bonus of R$ 10,000.00 for a tract but the maximum bonus offered among all bidders in that auction was equal to R$ 20,000.00, then its bonus would have obtained a score of 0.5, which would have contributed 0.5 * 40 = 20 to its final score. Thus, each bidder's score depended on the bids submitted by its competitors and a bidder reached a score of 100 only if it bid highest in the four items.

Once a tract was leased the winner was granted the right to explore it for a period lasting from two to nine years. If the firm does not explore it or does not find enough evidence of hydrocarbons in it to declare it commercially viable, the tract must be returned to the ANP, otherwise the lease can be renewed and production initiated. A fixed fraction of oil and gas revenues – the royalty payment – accrues to the government. Also, a retention fee is paid by the firm every year until the lease expires or production begins.

3. Data

We study bids for oil tracts in Brazil that were auctioned in ten annual rounds from 1999 to 2008. The data used are publicly provided by the ANP.[7] The unit of observation is either a bid or an auction for an oil tract. We have data on the 3,571 auctions held for 2,025 tracts and on the 1,279 bids offered in the 803 auctions that received at least one bid. Out of these 3,571 auctions, 2,025 offered tracts that had never been offered before and 858, 626, and 62 auctioned tracts that were offered once, twice, and three times before. Out of these 1,546 auctions of tracts that were previously offered, only 28 offered tracts that received bids in previous auctions. These were either cases in which the winner defaulted on its bid or where

[7] The data are available at www.anp.gov.br.

the tract was effectively leased but eventually returned to the ANP. Figure 1 presents the number of tracts auctioned by year and number of times previously offered. The large majority of auctions, 2,955, occurred in a short interval of time, between 2003 and 2005. Tracts auctioned once, twice and three times previously started to be offered, respectively, in 2004, 2005, and 2007. In 2004 and 2005 most tracts had already been offered before.

The data contain the following information for each auction: its year, the tract that was auctioned, the geographic basin where it is located, a dummy for whether it is located onshore or offshore, the number of bids, the minimum bonus required, the minimum technical qualification required from bidders, whether the winner eventually reported that hydrocarbons were found in the tract, the area of the tract in square kilometers, the annual retention fee per square kilometer, and the maximum period of exploratory activity. For each bid the data contain the auction it refers to, whether it was a winning bid, its score, the bonus offered, a dummy for whether the bidder was a firm alone or a joint venture, and in case of joint ventures with Petrobras, whether this firm would be the operator in the consortium if winning the lease. The data on auctions and bids are summarized in Tables 2 and 3, respectively.

Figure 2 shows the distribution of the number of bids by Petrobras's competitors in auctions in which this firm did and did not bid. Petrobras bid in 465 auctions and did not bid in the other 3,106. In both cases, its competitors did not participate in most auctions. Still, the data suggest that Petrobras's and its competitors' valuation of tracts correlate positively, as the distribution of the number of its competitors' bids in auctions in which it participated first-order stochastically dominates the same distribution in auctions in which it did not bid.

Although the winner in these auctions was the firm that scored the highest with its bid, we also analyze what determines the bonus offered, which is just part of the bid. Thus, to justify this approach, we show that the bonuses determine bidders' scores. Figure 3 presents the 1,279 bids offered. On the horizontal and the vertical axes we show the percentiles that correspond to the bid's bonus and score, respectively, among all bids in the respective auction. For instance, tract BM-C-8 was auctioned in 2000 and received two bids: a winning bid with a bonus of R$ 12.03 million and a score of 91.28 and a losing bid with a bonus of R$ 13.40 million and a score of 90.36. In the graph the Cartesian coordinates for these observations are, respectively, (50, 100) and (100, 50). The areas of the circles in the graph are proportional to the number of bids with such percentiles, to show the frequency of each pair.

Figure 3 shows that bonuses determined the scores. The bonuses' percentiles are mostly the same as the scores': 1,106 out of the 1,279 bids are on the 45 degree line on the graph, which corresponds to bids for which the bonus and the score are ranked the same. Out of the 748 bids in auctions with two or more bids, 575 lie on this line too. Most winners had also submitted the highest bonuses: the highest scores and the highest bids coincide in 763 out of the 803 auctions that attracted at least one bid and in 232 out of the 272 auctions that received two or more.

4. Impact of Private Information on Bids

In this section we use a theoretical model to predict how bidders would behave in these auctions. We assume that Petrobras was better informed about the value of the tracts than its competitors. Later in the paper we test these predictions with the data to evaluate whether this assumption is valid.

4.1 Model

The model we use is the noncooperative first-price, sealed bid model with asymmetric information studied by Wilson (1967), Weverbergh (1979), Engelbrecht-Wiggans, Milgrom and Weber (1983), Hendricks and Porter (1988) and Dubra (2006). The version we use here is identical to Hendricks and Porter's and for the sake of comparison we adopt their notation and closely follow their description, but we also shorten it and omit the proof of the main theorem. The reader should refer to that paper for more details.

We assume that firms' bidding behavior is independent across auctions. Specifically, we assume that (i) there are no information externalities between tracts auctioned in the same round, (ii) the bidding strategy of each firm in an auction depends only on the information about it and the competition in it, (iii) firms are risk neutral, and (iv) the bidding strategy of a firm in an auction does not consider the effect of its bid on its expected payoff from future auctions for the same tract. Assumption (i) can be justified by the fact that the auctioned tracts are located in an extensive area. Most tracts are distributed along the coast of Brazil, between the north and the southeast of the country, across a variety of geological basins. However, it must be observed that the changes in the disclosure of results implemented from the fifth round onwards, described in Section 2, reflected concerns that there could be informational externalities between auctions for tracts located close to each other that were offered in the same round. Assumption (ii) is supported by the low entry costs in these auctions and by the large number of firms that bid in them. However, we again recognize that the changes in the disclosure of results mentioned above could also have been intended to prevent punishment strategies in auctions in the same round.

Assumption (iii) is reasonable for multinational oil companies that were entering this newly opened market and even for smaller firms that aimed at less risky tracts. Moreover, the financial requirements imposed by the ANP on bidders were intended to select only well-capitalized bidders. However, we recognize a number of facts that indicate that bidders were risk-averse and budget-constrained. First, bidders often sorted themselves into joint ventures allegedly to diversify risks and to increase their joint budgets. Second, firms often advertise to investors their success in building diversified portfolios of tracts, suggesting that these investors value lower risk.[8] Third, the very decision to open oil and gas exploration and production to private and foreign firms was to a large extent driven by the need to attract more investments than Petrobras alone could make. Fourth, the evidence from other auctions where governments leased numerous and expensive rights show that budget constraints determine bidding behavior significantly.[9] We discuss this assumption again later in the paper.

[8] See for example OGX's institutional presentation to investors (OGX Petróleo e Gás, 2011).

[9] Cramton (1995), Salant (1997), and Bulow, Levin and Milgrom (2009) show that bidders' strategies were substantially determined by budget constraints in the Federal Communications Commission (FCC) spectrum auctions. In these auctions, however, budget constraints were particularly important because licenses were auctioned simultaneously.

Assumption (iv) implies that each firm's optimal bid in an auction is the same as if it knew that the respective tract would never be auctioned again if it did not receive any bids in the current auction. This assumption is adequate as long as bidders' risk-free discount rates are high, they believe there is a low probability that the tract will be reoffered, they believe there is a low probability that they will win it in a future auction conditional on being reoffered, they expect a low payoff conditional on winning it, and they do not hold private information about its value that could be revealed if they do not bid. Although we recognize that a more realistic assumption would be that bidders do consider the effect of their bids on future auctions for the same tract, we believe that the weight of possible future auctions is small in a bidder's current payoff function. Moreover, this assumption keeps the model relatively simple.

There are n uninformed bidders and one informed bidder, which in our setting we assume is Petrobras, for the reasons discussed in subsection 2.1. Let X and Z denote, respectively, the private and public signals on V, the unknown value of the representative tract. The informed firm observes the realizations of X and Z prior to bidding in the auction, while uninformed firms observe the realizations of Z only. Realizations of these random variables are denoted by lowercase letters. We treat z as given and we are explicit about the dependence of the distributions on its value, but for notational convenience, we suppress the dependence of bidding strategies on z. We assume that the information held by the informed firm is a sufficient statistic for the information obtained by the uninformed ones.

The real-valued, random variable $H = E[V|X, z]$ summarizes the information of the informed firm. H has an atomless distribution, $F(.|z)$, with finite mean, $\overline{\mathrm{H}}$. The strategy of the informed firm is defined as a function σ, which maps realizations of H, which in turn are associated with the realizations of X, into the nonnegative real numbers. We assume that $\sigma(h)$ is a differentiable, strictly increasing function on the range (R, ∞), where R is the reservation price, and denote its inverse function in this interval by $\tau(b)$. Ties at R are assumed to be settled by randomization.

The strategy of the uninformed firm i is a distribution function $G_i(.)$ over the nonnegative real numbers. Define $G(b) = G_1(b) \cdots G_n(b)$ as the distribution function of the highest bid submitted by the uninformed firms in the auction. Tract valuations of uninformed firms are given by $E[H|z]-c$, where c is a fixed nonnegative constant which can represent differences in costs between them and the informed bidder.

Define

$$\varphi(h)=exp\left(-\int_h^\infty \frac{f(s;z)\int_h^s F(u;z)duds}{cF(s;z)^2+F(s;z)\int_h^s F(u;z)du}\right).$$

Note that $\varphi(h)$ is equal to $F(h;z)$ when c is equal to zero. A Bayesian Nash equilibrium for the bidding game is an $(n+1)$-tuple of strategies $(\sigma^*, G_1^*, \dots, G_n^*)$ that maximize each firm's expected payoff conditional on its information and the strategies employed by other firms. The theorem below is exactly the same contained in Hendricks and Porter (1988), which is in turn a restatement of the theorem in Engelbrecht-Wiggans, Milgrom and Weber (1983) extended to auctions with asymmetric valuations.[10]

THEOREM: *The* $(n+1)$*-tuple* $(\sigma^*, G_1^*, \dots, G_n^*)$ *is an equilibrium point if and only if*

$$G^*(b)=\begin{cases}1, if\ b>\overline{\mathrm{H}}-c\\ \varphi\big(\tau(b)\big), if\ R<b<\overline{\mathrm{H}}-c\\ \varphi(R), if\ 0\le b<R\end{cases}$$

$$\sigma^*(h)=\begin{cases}E[H|H\le h;z]-c, if\ h>\hat{\mathrm{h}}\\ R, if\ \hat{\mathrm{h}}\ge h\ge R\\ 0, if\ h<R\end{cases}$$

where $\hat{\mathrm{h}}$ *solves* $E\big[H\big|H\le \hat{\mathrm{h}};z\big]-c=R$.

PROOF: See Hendricks and Porter (1988).

4.2 Predictions

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[10] See Dubra (2006) for a correction of the proof of uniqueness of equilibrium in Engelbrecht-Wiggans, Milgrom and Weber (1983).

Hendricks and Porter (1988) show that the model above yields the following four predictions, which we adapted to our setting to be tested with our data:

P1: *The event that the informed firm does not bid occurs less frequently than the event that no other firm bids.*

P2: *The informed firm wins at least one half of the tracts, conditional on the event that at least one firm bids.*

P3: *The bidding strategy of the informed firm is an increasing function of the public signal, when a higher signal is "good news".*

P4: *The private signal on profitability is correlated with the informed firm's bid and orthogonal to the maximum uninformed bid.*

These properties of the equilibrium, among others, are derived and discussed in Hendricks and Porter (1988), which the reader should refer to for more details.[11]

P4 demands a measure of private information on profitability, and we use the notification of hydrocarbons for this purpose for two reasons. First, this measure is adequate given the data limitations because firms can only produce oil or gas after reporting they found hydrocarbons in the tract. Second, although a direct measure of profitability based on actual oil and gas sales should be more accurate for the value of the tract, we cannot compute one because these auctions are too recent and thus only a few tracts have already produced hydrocarbons. Moreover, oil and gas sales figures correspond to *ex post* realizations of the value of the tract,

[11] These four predictions correspond respectively to predictions 1, 2 and 7 in Hendricks and Porter (1988) and to a prediction discussed on page 877 of that paper. The four remaining predictions, 3, 4, 5 and 6, cannot be properly tested with our data. Predictions 3 and 4 require an estimate of expected profits which cannot be built in our context because the large majority of tracts in our sample have not produced any hydrocarbons yet. Prediction 5 assumes that c is equal to zero, which is unrealistic given that Petrobras was an incumbent in this market. Prediction 6 ideally should be tested using data on the actual number of potential uninformed bidders in each auction, which we do not observe. Alternatively, we could use the number of uninformed bids as a proxy for the number of potential bidders, but we do not consider this to be an adequate measure in our setting. For instance, the large number of auctions that received bids from Petrobras above the reservation price but no bids from other firms suggests that in many cases the number of potential and effective uninformed bidders differed significantly.

and thus may contain more information about it than we assume that Petrobras's private signal did.

Notification of hydrocarbons, however, may not measure tracts' value accurately because these auctions were conducted recently, because of endogenous drilling decisions, and because less than half of the tracts offered were eventually leased. First, because tracts were auctioned recently, the exploratory period has not elapsed yet for many of them, implying that winners have already found hydrocarbons in only a few tracts – 158 out of 803 leased – and that they can still find it in tracts where they have not yet done so.

Second, the identity of the winner and its bid may be correlated with unobservable characteristics or events that determine whether tracts are drilled or not. For instance, they may be correlated with drilling capabilities, information acquired after auctions, and with information externalities and strategic interactions in drilling decisions among owners of neighboring tracts, which are known to have an impact on the timing of drilling (Hendricks and Kovenock, 1989; Porter, 1995). Indeed, Perez (2010) shows that Petrobras typically drills the onshore tracts it wins sooner than its competitors. For this reason, drilling decisions can be endogenously determined by unobservable characteristics of bidders.

Third, hydrocarbons can only be identified in tracts that were effectively leased, implying that we cannot know if they would be found in other tracts if they were explored. In the ANP auctions only 803 out of 2,025 tracts offered were leased. Therefore, any empirical evidence based on a sample restricted to leased tracts may be biased due to selection on unobservable characteristics that determine whether or not a tract receives any bids. Indeed, we show in Appendix A that empirical estimates of what determines competitors' bids differ significantly when we restrict the data to leased tracts compared to estimates based on a broader sample. For these reasons, we interpret skeptically the results that relate this variable to bidding behavior.

We then introduce one more prediction to be tested with observations of reoffered tracts. 28 auctions contained in our original dataset offered tracts that received bids in previous rounds and were auctioned again in future rounds, but we dropped them from our sample because the reasons why they were reoffered were unclear in some cases. The only cases of repeated tracts we use correspond to those that were offered in a past round, received no bids and were offered again later, which amount to 1,518 auctions. Thus, our prediction on repeated auctions must be designed for these cases exclusively.

In the model, we assume that the private information held by Petrobras is a sufficient statistic for the public information that other firms might have. Therefore, any information that these firms might have eventually revealed through their bids in an auction should not affect Petrobras's expectation about the value of the respective tract. On the other hand, Petrobras's bid in an auction should have caused its competitors to adjust their estimates because the model predicts that in equilibrium the informed bid increases with the private signal. In particular, if the informed firm does not bid in an auction, this implies that its expectation of the tract's value h is lower than the reservation price R. In this case, the public signal Z of a tract decreases, and then the uninformed firms should revise downwards their estimates of tract value. This reasoning together with the theorem above implies that an auction that does not attract any bids for a tract should not affect the informed bidder's decision to participate, but should make it less likely that any uniformed bidder participates in future auctions for the same tract. This happens because, from this discussion, auctions without bids lower Z but keep h unchanged, and the theorem states that the informed firm decides whether or not to bid taking only h into account, while uniformed bidders are less likely to bid the lower Z is.[12] Therefore, we establish the following prediction:

P5: *Uninformed firms are less likely to bid for tracts that had been offered before, while informed firms are equally likely to bid for new or reoffered tracts.*

This prediction, however, is subject to two caveats. First, it holds empirically only if tracts' characteristics are properly controlled for. Under these ideal circumstances, it implies that an

[12] This prediction could be refined to argue that Petrobras should have valued tracts more relative to its competitors the larger the number of times they had been auctioned before because each additional auction in which it did not bid for a tract should have caused its competitors to revise their estimates downwards again. However, we believe that most of the private information that Petrobras potentially had about tracts and that could be revealed through its bids was actually revealed the first time a tract was auctioned, and therefore its competitors would not update their estimates substantially if it did not bid for a tract for the second or third time.

indicator of previous auctions for a tract is orthogonal to informed bidder participation and negatively correlated with uninformed bidder participation. However, tracts that had been previously offered should have been valued less by any bidder on average because most likely they have negative characteristics that affected their bids. If we cannot observe these characteristics then the correlation of the indicator of previous auctions with uninformed bidder participation will be reinforced and the correlation with informed bidder participation will become negative too.

Second, this prediction was derived based on assumption (iv) discussed in the previous subsection. We assume that bidders do not consider the effect of their own bids on the probability that the respective tract will be offered again in the future. By assuming this we were able to generate this prediction using this static theoretical model instead of solving it in a dynamic framework where a tract could be offered repeatedly in case it did not attract any bids. We imposed this assumption to keep the model tractable and we believe that it is adequate for our setting. However, we do not have any strong evidence to support this assumption, and therefore we suggest that the results based on it be interpreted carefully.

5. Evidence

In this section we test the predictions from the previous section against the data. We start by investigating whether P1, P2, P4 and P5 adhere with sample statistics. We next test P3 and P5 using a simple bivariate probit model. We test P4 against sample statistics only, as opposed to estimating a structural model similar to Hendricks and Porter (1988), due to the limitations of the notification of hydrocarbons dummy and due to the selection bias caused by restricting the sample to leased tracts that we discussed before. We show in Appendix A that estimates of an empirical model similar to Hendricks and Porter's that restrict our data to auctions that received at least one bid differ substantially from estimates using auctions that did not receive any bids too, which indicates that the former would be biased.

5.1 Sample Statistics

We start by evaluating the predictions from section 4 based on evidence from sample statistics. The statistics in Table 4 provide some but not full support to the predictions. A total of 338 auctions received at least one bid but none from Petrobras, which is more than the number of auctions with bids from Petrobras but none from its competitors, equal to 286, therefore contradicting P1. On the other hand, consistent with P2, Petrobras won 403 tracts, which is slightly more than half of the 803 auctions that received at least one bid.

We now turn to P4, examining statistics from tracts won by Petrobras and its competitors in Table 5. Columns 1 to 5 correspond, respectively, to (1) tracts won by Petrobras either alone or in a consortium in which it was the only bidder, (2) all tracts won by Petrobras, (3) tracts won by its competitors in which there was only one bid, (4) tracts won by its competitors in which Petrobras bid, and (5) all tracts won by Petrobras's competitors.

The numbers support P4 and thus the hypothesis that Petrobras was better informed about tract profitability than its competitors: This firm reported that it found hydrocarbons in 95 out of the 403 tracts that it won, which is almost 50 percent higher than the figure for its competitors, equal to 63 out of 400. The ratio between Petrobras's average winning bid for tracts where hydrocarbons were eventually detected and the average of all its winning bids is equal to 1.83 (R$ 6,826.72 divided by R$ 3,731.42), which is also larger than the respective ratio for its competitors, equal to 1.47 (R$ 7,698.84 divided by R$ 5,220.36), consistent with P4.

The numbers in Table 4 also expose an interesting fact that supports the hypothesis that Petrobras held private information about tract profitability. While this firm and its competitors won roughly the same number of auctions – 403 against 400 – the latters' winning bids were significantly lower than the former's on average, namely, R$ 3,731.42 against R$ 5,220.36. The statistics are even more striking when we restrict our analysis to bids by Petrobras alone for offshore tracts. It bid on average lower than its competitors alone or in a joint venture, but it obtained an outstanding success rate of 132 wins out of 134 auctions in which it bid according to Table 5. This lower average winning bid can be explained by the distribution of Petrobras's and its competitors' bids for offshore tracts. Most tracts were leased with only a few bids:

among the 311 offshore tracts leased, 251 received a single bid, or 80.71 percent of them. However, the percentage of wins in which Petrobras alone was the only bidder is even higher: 126 tracts out of 132 wins, or 95.45 percent of the total. This difference in the distribution of bids impacts their values because the average winning bid in offshore tracts that received at least two offers was much higher than in those that received only one bid: R$ 34,702.91 against R$ 5,250.84, respectively, thereby explaining why Petrobras alone had such a high success rate while bidding lower than its competitors.

It remains to explain, however, why Petrobras alone was more likely to be the only bidder than its competitors: while the former was the only bidder in 126 out of 134 bids for offshore tracts, other firms alone or in joint ventures where the only bidders 56 times out of 156 bids. Two reasons may explain this. First, Petrobras already produced oil and gas offshore and had expertise in the offshore and deepwater drilling and production that are necessary for these tracts, and thus might have faced lower costs compared to its competitors. This cost difference in turn would have made its competitors less likely to bid for these tracts. Indeed, Table 6 indicates that Petrobras strongly preferred offshore tracts compared to its competitors: It bid in twice as many auctions for offshore tracts and in half as many auctions for onshore tracts as its competitors. Second, competitors may have avoided biding for tracts that they also expected Petrobras to bid on because the latter was better informed and for this reason they would have won only tracts that this firm considered less valuable.[13]

Table 6 presents the number of auctions that Petrobras and its competitors bid discriminated by the number of times the tract had been offered before and separated into offshore and onshore tracts. The numbers from both offshore and onshore tracts support P5. The ratio between auctions for offshore tracts that were never offered that received bids from Petrobras and from its competitors (215 over 105) is slightly lower than for tracts that had been offered before (25 over 11). Also, the ratio between auctions for onshore tracts that were never offered

[13] Hendricks and Porter (1988) used a similar argument based on the winner's curse to explain why wildcat tracts received on average more bids than drainage tracts despite the fact that latter were more than twice as valuable as the former. Information in wildcat auctions is essentially symmetric, while in drainage auctions neighbor firms have superior information about profitability compared to non-neighbor firms. For this reason, non-neighbor firms would avoid competing with neighbor ones for drainage tracts.

that received bids from Petrobras and from its competitors (129 over 288) is much lower than for tracts that had been offered before (85 over 96). These ratios indicate that Petrobras was relatively more likely than its competitors to bid for tracts that had been offered before as opposed to tracts that had never been offered, which is consistent with P5.

These results corroborate the hypothesis that Petrobras is better informed than its competitors, but also suggest that not all the assumptions embedded in the predictions are valid for the market we study. The data strongly support P4 and P5, which relate differences in bidding behavior across auctions to private information, but violate P1 and satisfy P2 by a slim margin only, which are the two predictions relating the total number of bids and wins to private information. These results indicate that at least one assumption of the theoretical model is not valid in this setting. Indeed, they corroborate the facts mentioned in Section 4 that suggest that the assumption that Petrobras was not constrained in its capacity to bid and explore a large number of tracts does not hold here. P1 and P2 rely heavily on this assumption because they predict the total number of bids and wins and for this reason they depend on the ability of this bidder to offer a large number of competitive bids, which may be the reason why the first prediction was violated and the second was barely satisfied. On the other hand, P4 and P5 – which are supported by the evidence – do not depend as much on this assumption: although the theoretical model does not allow us to draw conclusions about bidding behavior by budget-constrained firms, the logic driving these two predictions would still hold if bidders were constrained, because they dictate the relative behavior across auctions, as opposed to the total number of bids or wins.

5.2 Bivariate Probit Results

In this subsection we test P3 and P5 using the following bivariate probit model of bidder participation:

$$Y_{ij} = \Theta_i X_j + \eta_{ij}. \tag{1}$$

For competitor i, Y_{ij} is the latent value of bidding in auction j, Θ_i are the coefficients to be estimated, X_j is a vector of characteristics of the tract offered in auction j, and η_{ij} is a competitor-auction specific unobservable error. We assume that $i \in \{P, C\}$, where P is for Petrobras alone or in a joint venture and C is its competitor that offered the highest bonus for tract j alone or in a joint venture that does not include Petrobras. We assume that the error terms η_{Pj} and η_{Cj} are mean zero conditional on X_j and that they have a bivariate standard normal distribution. Define I_{ij} as the function that indicates if competitor i bid in auction j. We observe $I_{ij} = 1$ if $Y_{ij} \geq 0$ and $I_{ij} = 0$ otherwise.

Equation (1) does not control for bidders' characteristics that we observe in the bid data, namely, whether a bid by Petrobras was offered by this firm alone, as the operator in a joint venture, or as a non-operator in a joint venture, and whether the highest bid from its competitors was offered by a firm alone or in a joint venture. We cannot control for these characteristics because, of course, they are not observed when either Petrobras or its competitors do not offer a bid, and thus such information is missing for at least one of the two parties in every auction except those in which both Petrobras and at least one of its competitors bid. In order to investigate the impact of excluding these characteristics from (1), in Appendix B we compare the coefficients of truncated regressions of the bonuses offered with and without these characteristics. We find that the coefficients of tracts' characteristics remain roughly the same when bidders' characteristics are included in these regressions.

Bivariate probit analysis of bidder participation has a number of advantages. First, it is computationally simple. Second, it allows us to account explicitly for correlation in bidders' valuation of tracts. Third, because the dependent variable is whether or not a firm bid, it allows us to abstract from differences between bidders' bonuses and scores in auctions. Fourth, it uses both auctions that received and did not receive any bids, and therefore avoids the sample selection bias that we discussed before and examine in Appendix A.

In Table 7 we present the estimates for two different subsamples of auctions, namely, the 2004 and 2005 rounds, respectively. We do not use observations from all years in the same regression because many auctions reoffered tracts that were not leased in previous years, thereby violating the assumption of independence across observations. Thus, we guarantee independence by estimating the model separately for 2004 and 2005, the two years when the most tracts were offered and when the majority of tracts auctioned had been previously offered, allowing us to properly test P5.

The results support both P3 and P5. They show that Petrobras, the informed firm, is more likely to bid for tracts that require grade A qualification and with higher retention fees, which are positive public signals of tract value, and less likely to bid for offshore tracts, which are costlier to explore, develop and produce hydrocarbons from. These results therefore support P3 because they show that Petrobras is more likely to participate in auctions with favorable public signals of tracts' values.

Results from both subsamples support P5 too. The coefficients for the dummy for tracts that were previously offered are negative in both years for both Petrobras and its competitors, but they are significant for Petrobras's competitors only.[14] Thus, these estimates are consistent with other firms updating their estimates of tract value downward after they observe that a tract did not receive any bids in a previous auction. The estimates imply that tracts that have been offered before have a much lower chance of receiving any bids from Petrobras's competitors compared to those that are being offered for the first time. Among new tracts, the mean participation rates by these other firms were equal to 12.18 and 34.43 percent in 2004

[14] The coefficient of this dummy variable in the equation of Petrobras's competitors loses its significance if we also include the natural logarithm of minimum bonus as an explanatory variable. Moreover, in this case the estimates of its coefficients are significant for both years and both bidders. However, we believe this variable should not be included in the specification because its estimated impact most likely captures the impact of whether or not a tract had been offered before on bidder participation. First, the coefficients for the minimum bonus are positive in these specifications, indicating there is a positive correlation between bidder participation and minimum bonus, which is unintuitive unless the minimum bonus is positively associated with unobserved tract value. Second, a regression of minimum bonus on the explanatory variables used in Table 7 and with fixed effects at the tract level using all auctions in the sample indicates a strong negative relation between that variable and the dummy, thereby indicating that the minimum bonuses had been adjusted downwards for repeated tracts. This last result is consistent with theoretical results of optimal reserve prices in repeated auctions, such as in McAfee and Vincent (1997). The empirical results cited in this footnote were omitted from the paper for the sake of brevity, but are available from the authors upon request.

and 2005, respectively. According to Table 7, these probabilities would decrease to 4.55 and 22.36, respectively, if such a representative new tract were being reoffered instead.[15]

6. Conclusion

In this paper we tested predictions from one of the main models of auction theory with asymmetric information, using data from oil and gas tract auctions in Brazil, where the main winner was Petrobras, a national company. We assumed that this firm had superior information about tracts' values compared to its competitors and the results indeed indicated this is true. Bidders behaved closely to what the model predicted, which cannot be considered totally expected: despite its success in explaining bidding behavior in the OCS auctions, the model was not developed for an environment with the same characteristics as the Brazilian auctions and its results could be very sensitive to differences in these characteristics.

Our results, however, also suggest that not all the assumptions we imposed are valid for this market. While the results were mostly consistent with predictions about bidding behavior across auctions, the data either violate or satisfy by a slim margin only predictions about the total number of bids and wins. We interpret this as evidence that the assumption that firms were not constrained to bid and explore a large number of tracts might not hold in this setting. Therefore, these results reinforce the importance of budget constraints in large public auctions and the need to better incorporate these constraints in their study, as identified in other papers (e.g., Cramton ,1995; Salant ,1997; Bulow, Levin and Milgrom, 2009).

We also assumed that firms did not consider the effect of their bids on their expected payoff from future auctions for the same tract. This assumption was imposed mostly to keep our model tractable and was not contradicted by our findings. However, the literature on repeated

[15] We evaluate the impact of whether a tract had been previously offered on the participation decision of a bidder by considering the impact of this characteristic on a representative tract that had never been offered before. This tract is representative in the sense that its predicted probability of receiving a bid, conditional on having never been offered before, equals the mean participation rate in auctions for tracts that had never been offered before. Thus, the estimated effect is $\Phi(\Theta^* X + \delta^*) - \Phi(\Theta^* X)$, where X is such that $\Phi(\Theta^* X)$ equals this rate and δ^* is the coefficient estimate for the dummy for tracts that had been offered before.

auctions has shown that buyers may bid differently for the same good over time and that sellers respond strategically to it, defining how and which goods should be reoffered considering buyers' strategies (Ashenfelter, 1989; Black and de Meza, 1992; McAfee and Vincent, 1993; Cramton, 1995; Brusco, Lopomo and Marx, 2011). Relaxing these assumptions can be relevant for our understanding of bidding behavior under asymmetric information. We leave this point for future work.

Appendix A

In this appendix we show that the estimates of what determines bidding behavior differ when we restrict the data to auctions that received at least one bid. We compare estimates based on two samples. In the first we use all auctions that offered a tract for the first time and in the second we use a subsample of them restricted to auctions that attracted at least one bid. Both samples are restricted to auctions that offered a tract for the first time in order to guarantee that observations are independent within our sample.

The results indicate that restricting the sample to auctions that attracted bids biases the estimates due to selection on unobservable characteristics that determine whether firms bid. Restricting the sample to these auctions would be required if we decided to include in our regressions an independent variable that could be observed only if the tract was effectively leased, such as the notification of hydrocarbons dummy or any measure of ex post profitability based on the actual profit stream from a tract. We note, however, that this result is most likely driven by the fact that the ANP auctions attracted few bids compared to others such as the OCS auctions and therefore this result should not necessarily apply to other oil and gas lease auctions.

In order to investigate this issue, we estimate by maximum likelihood a bivariate model based on Hendricks and Porter (1988). Bids are determined by:

$$ln\left(\frac{B_{ij}}{R_j}\right) = Y_{ij}, \text{if } Y_{ij} \geq 0$$

$$= 0 \text{ otherwise} \tag{2}$$

where

$$Y_{ij} = \Theta_i X_j + \delta_{t(j)} + \varepsilon_{ij}; \tag{3}$$

B_{ij} is the bonus offered by bidder i in auction j, R_j is the reservation price of this auction, $\delta_{t(j)}$ are the fixed effects for auction j's year $t(j)$, ε_{ij} is a competitor-auction specific unobservable error, $i \in \{P, C\}$, and Θ_i and X_j are the same as defined in Section 5. The error terms ε_{Pj} and ε_{Cj} are distributed according to the covariance matrix Σ with variances σ_P^2 and σ_C^2, respectively, and coefficient of correlation ρ.

We partition the auctions into four mutually exclusive sets: Ω_{++} is the set of auctions in which both Petrobras and at least one of its competitors bid, Ω_{+0} is the set of auctions in which Petrobras bid but no competitor bid, Ω_{0+} is the set of auctions in which Petrobras did not bid but at least one competitor bid, and Ω_{00} is the set of auctions that received no bids. The log likelihood function can then be defined as:

$$logL = \sum_{j \in \Omega_{++}} l_{1j} + \sum_{j \in \Omega_{+0}} l_{2j} + \sum_{j \in \Omega_{0+}} l_{3j} + \sum_{j \in \Omega_{00}} l_{4j}, \tag{4}$$

where

$$l_{1j} = -\left[ln(2\pi) + \frac{1}{2} ln|\Sigma|\right] - \frac{1}{2}\left[\varepsilon_{Pj}, \varepsilon_{Cj}\right]\Sigma^{-1}\left[\varepsilon_{Pj}, \varepsilon_{Cj}\right]',$$

$$l_{2j} = ln\left(\Phi\left(\frac{-\alpha_P - \Theta_P X_j - \delta_{t(j)} - \sigma_{PC}\sigma_P^{-2}\varepsilon_{Pj}}{\sqrt{\sigma_C^2 - \sigma_{PC}^2\sigma_P^{-2}}}\right)\right) - ln(\sigma_P) + ln\left(\phi\left(\frac{\varepsilon_{Pj}}{\sigma_P}\right)\right),$$

$$l_{3j} = ln\left(\Phi\left(\frac{-\alpha_C - \Theta_C X_j - \delta_{t(j)} - \sigma_{PC}\sigma_C^{-2}\varepsilon_{Cj}}{\sqrt{\sigma_P^2 - \sigma_{PC}^2\sigma_C^{-2}}}\right)\right) - ln(\sigma_C) + ln\left(\phi\left(\frac{\varepsilon_{Cj}}{\sigma_C}\right)\right),$$

$$l_{4j} = ln\left(\Phi_2\left(\frac{-\alpha_P - \Theta_P X_j - \delta_{t(j)}}{\sigma_P}, \frac{-\alpha_C - \Theta_C X_j - \delta_{t(j)}}{\sigma_C}; \rho\right)\right), \tag{5}$$

and Φ, ϕ, and Φ_2 are, respectively, the standard univariate normal distribution, the standard normal density, and the standard bivariate normal distribution functions.

When using the subsample of auctions that received at least one bid, our log likelihood function must account for the truncation of tracts with no bids. The log likelihood is then rewritten as:

$$logL^c = \sum_{j \in \Omega_{++}} l_{1j}^c + \sum_{j \in \Omega_{+0}} l_{2j}^c + \sum_{j \in \Omega_{0+}} l_{3j}^c, \tag{6}$$

where

$$l_{kj}^c = l_{kj} - ln\left(1 - \Phi_2\left(\frac{-\alpha_P - \Theta_P X_j - \delta_{t(j)}}{\sigma_P}, \frac{-\alpha_C - \Theta_C X_j - \delta_{t(j)}}{\sigma_C}; \rho\right)\right), \tag{7}$$

and l_{kj}, $k \in \{1,2,3\}$, are the same as defined in (5).

Table A1 reports the estimation results for equations (2) and (3). In these specifications we assume that the vectors of coefficients Θ_C and Θ_P are equal, but allowing them to differ between bidders would not change our conclusions.[16] The first column shows the results using all auctions of tracts offered for the first time and the second restricts them to those that received at least one bid. The coefficients differ substantially depending on the sample used. The coefficient for retention fees is twice as large and significant when the broader sample is used compared to the restricted sample. The coefficient of exploratory period is four times as large if we use tracts that received bids only. The dummies for offshore tracts, and A and B qualification tracts are also much larger when the restricted sample is used. In summary, these results suggest that restricting the sample to auctions that attracted at least one bid biases the estimates most likely due to selection on unobservable characteristics.

[16] These results are available upon request from the authors.

Appendix B

In this appendix we investigate how controlling for bidders' characteristics impacts the estimates of the bid function. We compare the results of truncated regressions of the bonuses offered with and without these characteristics. We estimate by least squares a truncated regression model similar to (2) and (3):

$$ln(B_{ij}/R_j) = \alpha + \Psi W_i + \Theta X_j + \delta_{t(j)} + \varepsilon_{ij} \quad (8)$$

where Ψ is a vector of coefficients to be estimated, W_i is a vector of competitor i's characteristics, and the remaining variables and coefficients the same as in (2) and (3). The vector W_i contains four dummy variables corresponding to the cases in which the bidder is Petrobras alone, Petrobras in a joint venture as an operator, Petrobras in a joint venture as a non-operator, and a joint venture without Petrobras. Other firms biding alone are left as the reference case. i now indexes all bidders, instead of Petrobras and its competitor offering the highest bid, implying that we now include in our sample every bid, instead of Petrobras's and the maximum bid in each auction among its competitors'. The least squares estimation accounts for the fact that observations of B_{ij} lower than R_j are truncated.

Table A2 reports the estimation results for equation (7). The four columns show the results for samples of bids determined by bidders' characteristics. Columns 1 and 2 use bids offered by Petrobras alone or in a joint venture and columns 3 and 4 use bids by other companies. The odd columns do not control for competitors' characteristics within each sample while the even ones do. Column 2 includes dummies for Petrobras alone and as the operator in a joint venture leaving this firm as non-operator in a joint venture as the reference case. Column 4 includes a dummy for whether other firms bid alone or in joint ventures. The samples are also restricted to auctions that offer a tract for the first time. Observations are clustered by tracts to obtain robust standard error estimates.

The results show that for both subsample of bidders, controlling for participation in joint bids does not significantly affect the results. Although the dummy variable for Petrobras as the operator in a joint venture is significant at the five percent level in column 2, the estimates in columns 1 and 2 are quite similar for most coefficients and the same can be said about columns 3 and 4.

Estimating this equation by least squares presents a number of limitations. This method does not use the information contained in auctions without any bids, does not allow us to estimate the correlation among the errors in bids by different competitors, and it does not account for the fact that only auctions that received at least one bid could by selected into the samples. Indeed, Petrobras and its competitors bid in only 465 and 517 auctions, respectively, out of the 3,571 held, and for the estimation in Table A2 we use data from only 344 and 393 auctions, respectively. Arguably, parameter estimates based on these subsamples may be biased. For this reason the results in this table should be used only to examine how important it is to control for bidder's characteristics.

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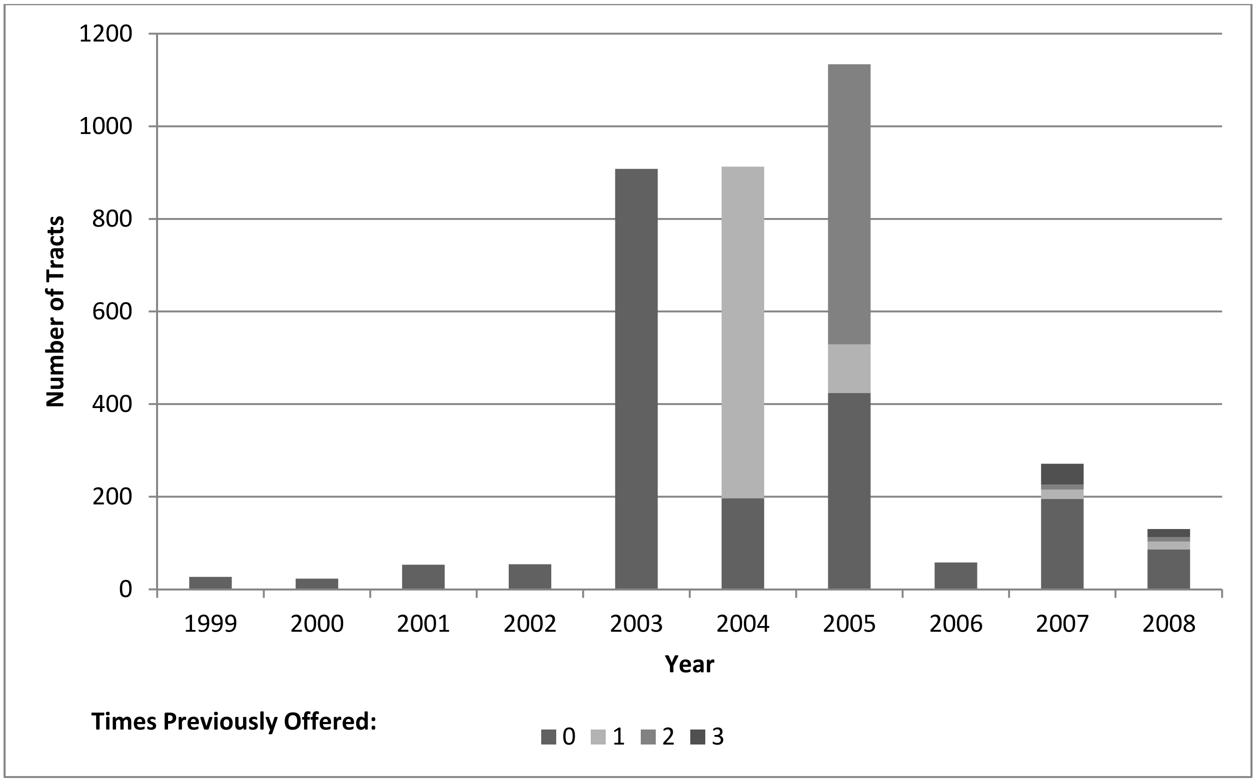
Figure 1

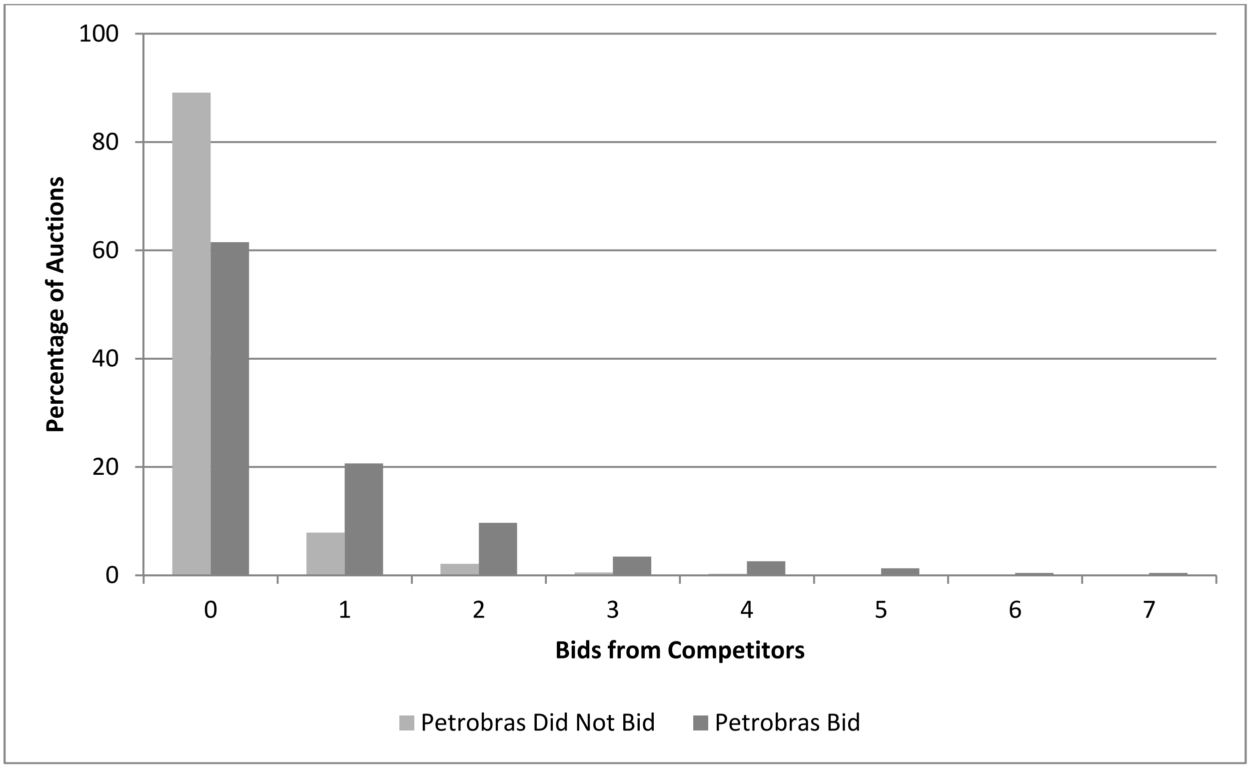
Tracts Auctioned by Year and Number of Times Previously Offered



Source: ANP.

Figure 2

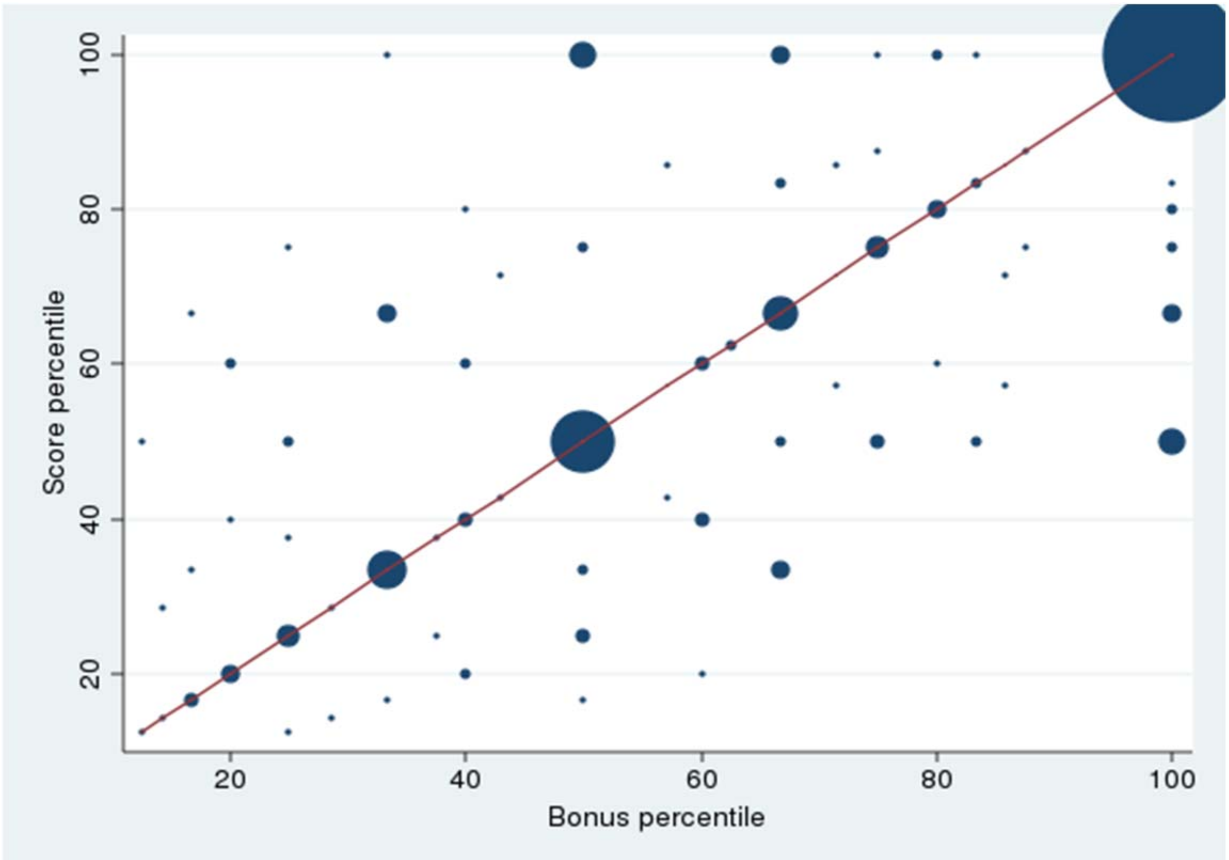
Distribution of Bids



Source: ANP.

Figure 3

Distribution of Bonuses and Scores



Source: ANP.

Table 1: Score Weights by Round

Rounds	Bonus	Minimum Exploratory Program	Domestic Content of Inputs			
			Total	Track Exploration	Field Development	Min. and Max. Limits
1 to 4	85	0	15	3	12	None
5 and 6	30	30	40	15	25	Min. only
7 to 10	40	40	20	5	15	Min. and Max.

Source: Reproduced from Perez (2010) based on ANP data organized by CEP-IBRE/FGV.

Table 2: Summary Statistics of Auctions

Variable	Mean	Std. Dev.	Min	Max
Petrobras' bonus (R$ thousand)	532.82	4,572.06	0.00	105,751.50
Maximum bonus by other firms (R$ thousand)	650.97	6,521.50	0.00	163,499.60
Minimum bonus (R$ thousand)	275.01	1,029.24	3.80	16,141.66
Petrobras bid	0.13	0.34	0	1
Number of bids by other firms	0.23	0.67	0	7
Area (km2)	377.27	923.13	6.12	15,292.00
Retention fee (R$/km2/year)	163.27	135.07	11.65	368.42
Offshore tract	0.62	0.49	0	1
New frontier	0.11	0.31	0	1
A qualification	0.14	0.35	0	1
B qualification	0.49	0.49	0	1
C qualification	0.38	0.48	0	1
Maximum period of exploratory activity	4.97	1.68	2	9
Times offered before	0.64	0.83	0	3
Hydrocarbons reported	0.04	0.21	0	1
Number of tracts	2,025			
Number of auctions	3,571			

Note: Real (R$) figures are normalized by the year 1998 values.

Table 3: Summary Statistics of Bids

Variable	Mean	Std. Dev.	Min	Max
Bonus (R$ thousand)	3,767.84	13,389.29	5.12	163,499.60
Minimum bonus (R$ thousand)	394.52	1,303.03	4.33	16,141.66
Petrobras alone	0.19	0.39	0	1
Joint bid with Petrobras as operator	0.09	0.29	0	1
Joint bid with Petrobras as nonoperator	0.08	0.27	0	1
Joint bid without Petrobras	0.16	0.37	0	1
Other bidder alone	0.48	0.50	0	1
Number of tracts	803			
Number of bids	1,279			

Note: Real (R$) figures are normalized by the year 1998 values.

Table 4: Sample Statistics on Tracts Won by Each Type of Bidder

Variable	Winner with Petrobras		Winner without Petrobras		
	Only One Bid	Total	Only One Bid	Petrobras Bid Too	Total
Number of tracts	286	403	245	62	400
Number of tracts where hydrocarbons were found	60	95	33	13	63
Average winning bid (R$ thousand)	2,306.08	3,731.42	2,930.76	15,132.72	5,220.36
Average winning bid in tracts where hydrocarbons were found (R$ thousand)	3,163.27	6,826.72	3,477.52	12,425.17	7,698.84

Note: Real (R$) figures are normalized by the year 1998 values.

Table 5: Sample Statistics of Bids for Offshore Tracts

Variable	Petrobras		Other Firms		All Firms
	Alone	Joint Venture	Alone	Joint Venture	
Number of bids	134	106	108	48	396
Number of wins	132	85	68	26	311
Number of wins as the only bidder	126	69	45	11	251
Average winning bid as the only bidder (R$ thousand)	1,650.66	6,055.66	11,899.18	14,243.24	5,250.84
Average winning bid for tracts with two or more bids (R$ thousand)	26,544.85	37,992.37	41,369.15	24,235.82	34,702.91

Note: Real (R$) figures are normalized by the year 1998 values.

Table 6: Bids by the Number of Times Tracts Were Previously Offered

Number of Times Previously Offered	Offshore			Onshore		
	Petrobras Bid	Other Firms Bid	Number of Auctions	Petrobras Bid	Other Firms Bid	Number of Auctions
0	215	105	1,152	129	288	873
1	22	9	563	49	52	276
2	2	1	455	30	36	165
3	1	1	37	6	8	22

Note: Tracts that were previously offered and received any bids were removed from the sample used above.

Table 7: Bivariate Probit Analysis of Bidder Participation

Variable	2004 Auctions		2005 Auctions	
	Petrobras	Other Firms	Petrobras	Other Firms
Ln(area)	0.266	0.493	-0.104	0.452
	(0.317)	(0.423)	(0.154)	(0.163)***
Ln(retention fee)	-0.154	1.010	3.519	1.814
	(0.147)	(0.754)	(0.687)***	(0.684)***
Offshore tract	-0.040	-5.785	-11.943	-7.125
	(0.797)	(2.833)**	(2.260)***	(2.199)***
Ln(exploratory period)	-2.126	2.443	8.708	3.705
	(1.008)**	(2.722)	(2.099)***	(2.092)*
A qualification	1.535	-0.092	0.311	-0.550
	(0.444)***	(0.744)	(0.264)	(0.284)*
Previously offered	-0.200	-0.524	-0.111	-0.356
	(0.185)	(0.199)***	(0.132)	(0.118)***
Constant	1.245	-8.864	-24.441	-13.465
	(1.657)	(5.806)	(4.744)***	(4.702)***
Coefficient of correlation	0.329		0.450	
	(0.099)		(0.070)	
Number of observations	913		1,132	
Log pseudolikelihood	-449.59		-625.60	

Note: All regressors are the natural logarithms of the respective variable with the exception of dummy variables. Standard errors are in parentheses. *, ** and *** denote significant at the 10, 5 and 1 percent level, respectively.

Table A1: Determinants of Bonuses

Variable	All New Tracts	Tracts with Bids
Ln(area)	0.652	0.758
	(0.094)***	(0.187)***
Ln(retention fee)	0.322	0.159
	(0.161)**	(0.338)
Offshore tract	-0.822	-4.604
	(0.780)	(1.646)***
Ln(exploratory period)	-1.682	-6.605
	(0.499)***	(1.169)***
A qualification	-0.579	4.411
	(0.787)	(1.493)***
B qualification	-0.998	3.105
	(0.714)	(1.307)**
standard deviation of Petrobras	3.370	3.210
	(0.120)	(0.134)
standard deviation of competitors	2.670	2.533
	(0.096)	(0.180)
coefficent of correlation	0.310	0.259
	(0.040)	(0.068)
Number of observations	2,025	603
Log likelihood	2,806.00	-1,707.34

Note: All regressors are the natural logarithms of the respective variable except for the dummy variables.
Standard errors are in parentheses. *, ** and *** denote significant at the 10, 5 and 1 percent level, respectively.
All specifications include year fixed effects, which are assumed to be equal for Petrobras and other firms.

Table A2: Robustness of Truncated Regressions of Bonuses

Variable	Petrobras	Petrobras	Other Firms	Other Firms
Ln(area)	0.231	0.217	0.092	0.088
	(0.159)	(0.165)	(0.251)	(0.250)
Ln(retention fee)	-0.432	-0.326	-1.031	-1.020
	(0.233)*	(0.234)	(0.396)***	(0.397)***
Offshore tract	-2.165	-2.363	0.946	0.852
	(1.550)	(1.456)	(1.348)	(1.340)
Ln(exploratory period)	-3.400	-3.229	-5.196	-5.193
	(1.128)***	(1.138)***	(1.434)***	(1.433)***
A qualification	2.012	1.686	5.141	5.253
	(1.253)	(1.237)	(1.306)***	(1.306)***
B qualification	1.631	1.343	3.827	3.898
	(1.150)	(1.122)	(1.085)***	(1.071)***
Petrobras alone		0.577		
		(0.335)*		
Joint bid with Petrobras as operator		1.037		
		(0.434)**		
Joint bid by other firms				-0.153
				(0.301)
Number of observations	344	344	639	639
Number of tracts	344	344	393	393
Log pseudolikelihood	-484.45	-480.98	-870.29	-870.19

Note: All regressors are the natural logarithms of the respective variable with the exception of dummy variables.
All specifications include year fixed effects.
*, ** and *** denote significant at the 10, 5 and 1 percent level, respectively.