Scoring Auctions, Investment and Production Outcomes: the case of Oil Leases in Mexico

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Mexico recently used auctions to allocate oil and gas leases for onshore fields. Companies submit as their bid royalties they will pay the government in addition to what is required by law, and additional investment to a minimum work program. Bids are transformed into a score and the company with the highest score wins the auction. This paper analyzes the effect of changing the scoring rule on investment and the expected government revenue. My model specifies the value of an oil field as a function of bid dimensions, and derive equilibrium conditions using results from the scoring auction literature. Using auction data and the investment plans from companies, I estimate the distribution of the cost of investment for bidders. I then simulate different counterfactual results. First, I use a rule where the trade-off between bid dimensions is constant (used initially in Mexico). In this case, as the weight of investment increases, there are two opposite effects: increase in investment and production but lower royalties per barrel. Initially, the effect of increased investment is larger but then the effect of lower royalties per barrel becomes larger, and government revenue declines. I also compare is between the original rule used by the Mexican government, and the new rule, where bid dimensions are complementary (trade-off is not constant). In this case, adopting the new rule implied that revenues would have increased by $150 MM approximately. This suggests that having less extreme combinations of bid dimensions could increase the tax base.

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1 Introduction

Auctions for oil and gas leases in Latin America have become more frequent in recent years, as countries like Brazil and Mexico changed legislation governing the oil and gas industry to allow more private sector participation [2].

State ownership of resources in these countries enables government to play a more direct role in resource exploitation, although the resulting policies may have multiple objectives. One interest for policy makers is collecting revenue from selling prospective exploration and production ($E\&P$) blocks, and taxing any subsequent production from those blocks. Another goal could be to encourage exploration of the country, especially in frontier areas where exploration outcomes can generate substantial information about potential resource endowments, and thereby provide positive externalities to other potential investors. Governments may also want to encourage hydrocarbon resource development to provide growth opportunities for local goods and services providers, and stimulate broader economic growth or satisfy other industrial policy objectives.

One way of including multiple objectives is through a scoring auction. In a scoring auction, multidimensional bids are ranked by converting them to a score using a previously specified formula. Countries differ in the type of scoring rule they use or the variables included as bid dimensions. Also, the weights in the score are chosen to reflect the different policy objectives of the government. My research looks at how changing the scoring rule affects investment and production outcomes when allocating oil and gas leases.

In the particular case of oil leases in Mexico, companies submit a bid containing additional royalties to the ones established by law [3], as well as investment commitments in addition to a minimum work program. Through the use of a scoring rule, the government decides the winner. The scoring rule changed in recent auctions to put a higher weight

[2]"Brazil vs. Mexico: Latin America's fight for Big Oil's money". Thomson Reuters, October 26, 2017

[3]In Mexico, the State owns mineral rights (including those from oil), which is why royalties are paid to the government in the form of taxes. This is different to the U.S., where in most cases, royalties are paid to landowners, with the exception of federal leases.

on the investment component. One concern for the Mexican government will be the total effect on tax revenues from changing the scoring rule: on the one hand, higher tax rates imply a higher fraction of revenue being collected, but also reduced cash flow for investment, which affects production levels (and the tax base), during the lease period. Understanding the trade-off between bid dimensions enables measurement of the effects of taxation on the performance of the sector.

This research focuses on onshore oil and gas fields in Mexico. The allocated blocks in this case are mature fields with a long history of production, more knowledge about the potential resources compared to other types of fields (such as shallow or deep water), and more infrastructure in place. Because of this, most of the investment made for these blocks has a direct effect on oil and gas production. This provides an explicit link between the investment committed during the auction stage to production (and profits, under some price and cost assumptions) during the drilling stage. In this way, the value of the auctioned object is a function of the auction results (and influenced by the auction design).

I propose an empirical model that uses information on bids, production forecasts and investment plans of winning companies to connect auction design with investment and production activity. This model allows me to analyze the effect of changing the scoring rule on the amount of investment and future production, as the bidder value of the block will be a function of its (i) expectations of the quantity of oil, (ii) type of work performed on the fields and its cost, (iii) beliefs about future oil prices, and (iv) residual claims on oil revenues. I rely on a functional relationship between the investment offered in the auction and the following increase in production by each block to identify the cost of this investment by firm, and estimate a distribution of scores as a function of the cost type, in order to perform counterfactual simulations. Specifically, I estimate the effects on government revenue, investment units and oil production from different scoring rules.

The empirical model is related to the framework developed by Hanazono, Hirose, Nakabayashi and Tsuruoka (2016) to study scoring auctions. Specifically, they provide a general model that summarizes a broad class of scoring rules in settings with multidimensional signals. I extend their analysis by including post-auction effects from different auction designs. My approach is also related to the work of Lewis and Bajari (2011), who study scoring auctions for procurement contracts. They analyze the effects of optimal weights in the scoring rule on outcomes such as completion time for projects. My research extends their work by providing a model for the auction stage, which allows me to recover the distribution of cost types from bid and post-auction data.

Section 2 presents a literature review on scoring auctions and contingent payment auctions. Section 3 introduces the model and equilibrium conditions for this game. Section 4 presents the data, institutional context and reduced form estimations addressing the effect of the change in the scoring rule.

2 Related Literature and contributions of this research

2.1 Scoring Auctions

The seminal work of Che (1993) led to several theoretical and empirical studies of scoring auctions. Most of these studies focused on procurement auctions, where firms bid on dimensions such as the price of the job, but the score also is a function of different quality attributes of the bidders.

The benchmark model by Che (1993) opened several lines of research. First, it formally established a model for the scoring auction. Second, it presented a set of functional forms for buyer preferences and firms' costs that can be used for structural estimation. In his model of a procurement auction, a buyer has preferences over price and quality, and firms (which are the bidders) have private information about the costs of improving quality.

Under some regularity assumptions about firms' costs, the author shows that the optimal outcome can be achieved through a scoring auction.

Three two-dimensional auctions are considered, in which the firm with the highest score wins the auction. The first is a first-score auction, where each firm submits a sealed bid and, upon winning, produces the offered quality at the offered price. Next, Che (1993) considers a second-score, in which the winner is required to assent to a contract offering any quality-price combination that matches the highest rejected score. The third auction type is a second-preferred-offer auction, which requires the winner to match the exact quality-price combination of the highest rejected bid. Che (1993) shows that if the buyer can only credibly commit to a scoring rule that reflects its true preference ordering, then all three scoring rules yield the same expected utility for the buyer.

Milgrom (2004) compares English ascending auctions and scoring auctions, to study the effect of auction design on entry conditions. He shows that when auctioneers value non-price attributes, the introduction of a scoring rule increases the expected maximum value. The intuition is that scoring auctions encourage a more complete comparison of the attributes of suppliers and products, relative to an auction based solely on bid price. Therefore, scoring auctions may increase bidders' expected profits and encourage participation by more bidders.

Asker and Cantillon (2008) show that the results from Che (1993), with one-dimensional quality, can be extended to a multi-dimensional quality setting by defining a "pseudo-type". A pseudotype is a function that relates the optimal quality that suppliers offer in the auction to a signal they observe. The authors show that there is no loss of generality in concentrating on pseudotypes when deriving the equilibrium in the scoring auction, even if the scoring rule does not correspond to the buyers true preference.

The results of Hanazono et. al (2016), on the identification and estimation of scoring auctions, provide a general framework for investigating independent scoring auctions. In this subset of scoring auctions, the score a firm obtains is only a function of its own bid and does not depend on other firms bids.[4] Hanazono et. al (2016) show the existence of a unique monotone equilibrium that under some assumption. Moreover, they provide necessary and sufficient conditions on bidder cost functions for the identification of the distribution of cost efficiency from scoring auction data. The most important condition is on the functional form of the cost function, which not only has to be quasilinear, but also satisfy an analogous condition to strong separability.[5] Using a cost function that satisfies this property, and using price and quality data, cost types for the bidders can be identified. Applying their model to data on Japanese procurement projects, they estimate the impacts of changing auction formats and scoring rules. Counterfactual analyses suggest that the changes in auction formats (first-score vs second-score (SS) auctions) and scoring rules have limited impact on utilities of both the procurement buyer and suppliers. The gain from using the scoring auction instead of conventional price-only auctions has, on average, greater impact on both buyer and contractor welfare. However, the numbers vary depending on the quality standards set in price-only auctions, Quality of standards are, of course, chosen by the contractors in the scoring auction.

My research extends the model of Hanazono et. al (2016), to include ex-post outcomes from different scoring rules. This extended framework allows also consideration of the effect of changes in oil and gas price trajectory, or different cost assumptions, on counterfactual bids. Unlike the model developed by Hanazono et. al (2016), and the work on procurement auctions previously developed, my research adapts their framework to the oil and gas case.

In the case of energy, some authors (IRENA, 2015) argue that multi-criteria auctions (such as the scoring auctions) are similar to introducing soft qualification requirements (such as minimum work programs), as bidders that meet certain desirable qualities receive

[4]By contrast, in an interdependent scoring auction, the score a firm obtains not only depends on its own bid but also from the competing bidders. In the oil and gas case, Brazil provides an example of such an interdependent scoring rule. See SantAnna (2017) for details

[5]For a definition of strong separability, see Berndt and Christensen (1973)

bonuses for the purpose of bid comparison. However, Ausubel and Cramton (2012) point out that the use of scoring auctions assumes that all criteria used to base the decision (the bid dimensions) upon are quantifiable and objective. This implementation also assumes that governments fully understand the tradeoffs across all factors when that may not be the case. Bidders possessing better information than the government can exploit that to their advantage.

Scoring auctions for selling oil and gas leases are different to procurement auctions, in the sense that bidders do not receive monetary compensation, but rather win a block that has some value to them.

Sant'Anna (2017) provides one empirical application of scoring auctions to the oil and gas case. He examines exploratory blocks in Brazil (with no previous production history, infrastructure and basic geological knowledge). The scoring rule includes dimensions such as: signature bonus, exploration effort and percent of goods bought from local companies when investments are made in the field. The score for any given company depends on the entire vector of bids, including those from competitors, unlike all the previous cases discussed above.

Sant'Anna (2017) provides equilibrium conditions needed to enable estimation of the cost types for exploration and the value of the oil and gas field from bid data. These are analogous to the conditions given by Guerre, Perrigne and Vuong (2000) for the case of price auctions. Sant'Anna (2017) uses the estimates of the value of the block and cost of exploration for counterfactual simulation. In particular, he compares the outcomes of the scoring auction against a first-price bid auction, where the exploration effort is fixed and the winner is the bidder with the highest signature bonus. The results showed that the scoring mechanism had higher average exploration than the fixed exploratory effort, while the offered bonuses were similar. This means that the scoring auction is no worse than the first-price bid auction with a fixed level of exploration.

One particular concern about the model is that Sant'Anna (2017) does not attempt to show the existence of equilibria in this setting, or the uniqueness of an equilibrium (if it exists). Because the author does not prove the existence of a unique monotone equilibrium in this model, it is not clear whether different combinations of signature bonus and investments could lead to the same value of the block, that is, the model may not be identified from data. Also, by not addressing questions regarding the existence of multiple equilibria (which can be present in interdependent scoring auctions), the results regarding counterfactual simulation may not necessarily be true, as the equilibrium may change with a different setting, vitiating the comparison between outcomes under different rules.

In my research, I assume that conditions for the existence and uniqueness of an equilibrium hold, thus ensuring identification of the model. I provide a discussion on the steps for a formal proof of the existence and uniqueness of the equilibrium for this model. Most of the literature on oil and gas leases assumes the value of the block as exogenous, including Sant'Anna (2017), considers the value of the block to be exogenous. [6] My research explains the value of the block a function of the investment and royalties offered in the auction stage. To my knowledge, this is the first model to include the effect of investment on oil production, and subsequently, on the value of a block for bidders.

In this sense, my research is also related to the relationship between the scoring auction and ex-post outcomes.

2.2 Scoring Auction design and ex-post outcomes

Lewis and Bajari (2011), which examines highway procurement auctions, is the first structural analysis on scoring auctions . The scoring rule they examine is of the type "A+B". Contractors submit a dollar bid for labor and materials, the "A" part, and a total number

[6] One exception is the work of Bhattacharya, Ordin and Roberts (2018). They provide a model in which the value of an oil block is a function of drilling profits, where oil prices are random and the quantity of oil is considered fixed

of days to complete the project, the "B" part. The project is awarded to the contractor with the lowest score using both the A and the B bid. The model characterizes equilibrium bids and project completion times, allowing also for endogenous participation. This paper also addresses the question of optimal weights. They show that the time weight in the A+B scoring rule acts like a tax, reflecting the social cost of increased traffic due to slow completion of projects. The scoring rule gives contractors explicit incentives for accelerated delivery, as they internalize the externality.

Another contribution that relates changes in weights to scoring auction outcomes is Koning and van de Meerendonk (2014). They analyze procurement of Welfare-to-Work contracts, in which the dimensions in the scoring auction include: prices, and three proxies for the quality of service. They exploit changing weights of the scoring rules over time to perform "difference-in-difference" analysis for contracted worker-group types on a number of relevant outcome measures. They also account for selection effects of changing the weights, as doing so may induce or retard participation of specific types of organizations. As expected, increases in weights for quality proxies result in higher price bids, particularly for new entrants. In terms of objectives for the auctioneer, higher scoring weights on quality attributes (such as reputation and plans to reintegrate workers), improve the job placement rates of firms that have won the procurement. All of this suggests potential trade-offs of price and quality when analyzing procurement auctions.

Bajari, Houghton and Tadelis (2014) attempt to measure the economic costs of ex-post adaptations that result from incomplete procurement contracts. Adaptation costs are incurred by disruptions to the normal flow of work that could have been avoided with adequate planning in advance. In order to estimate the magnitude of adaptation costs as a markup over production costs, they develop a structural model of a scoring auction that incorporates an anticipated use of inputs before completing a project and ex-post quantities that were actually used when completing the project. This scoring auction model is similar to the model of Che (1993) in that the choice of the score is separable from the optimal choice of the actual bid vector.

Huang (2017) studies “quality manipulation corruption” in a scoring auction. Quality manipulation arises when quality is difficult to assess and the procurement agency is bribed to misreport the true quality of a firm. The model is nonparametrically identified and structurally estimated from a quasilinear scoring auction [7] to recover cost types and social surplus. Her structural analysis also develops tests for quality manipulation corruption. Unlike previous studies, this paper does not assume any parametric form for the costs. The paper also shows how weights in the scoring auction may affect the presence of corruption. Results from the structural model suggest that a higher quality weight in the scoring rule gives more room for quality manipulation. This is because the possible gains for firms from bribing the auctioneer increase with the weight on quality. This suggests that when choosing weights, authorities need to address efficiency concerns but also distortions that may appear in the implementation phase.

Bolotnyy and Vasserman (2018) use a similar formulation to Bajari et al. (2014) to study the effects of risk aversion in procurement auctions, and how it explains bid skewing in the auction stage. In their case, there is also uncertainty regarding the actual quantities being used in a project. The score is calculated as the unit cost of inputs in a project, multiplied by some engineer estimates of quantity. This allows the authors to model profits after the auction as a function of the bid dimensions, incorporating uncertainty about the actual quantities of inputs used in the project. They also show equilibrium conditions for the auction stage, by separating the auction in two stages: choosing a score after knowing their efficiency type, and then choosing an optimal bid for a given score.

My model is similar in spirit to those of Lewis and Bajari (2011), Bajari, Houghton and Tadelis (2014) and Bolotnyy and Vasserman (2018). It develops a more general framework for the auction stage, because it allows for non-quasilinear scoring rules (although in the specifc case of Mexico, the scoring rule is quasilinear). It is also more concerned than

[7] A scoring auction is quasilinear if the scoring rule is quasilinear.

are these papers with examining counterfactual simulations regarding different scoring weights.

2.3 Auctions, taxation and investment in the oil and gas sector

Based on experiences drawn from several countries, Tordo et al. (2010) draws some general lessons for the applicability of auctions in allocating oil and gas leases:

- The relative maturity of a geological basin affects the amount of geological knowledge and risk, the level of competition and the size of the winning bid.
- Expected future oil and gas prices are a significant factor in explaining the variability over time in the number of bids and bid size for the same geological basin.
- The number of bidding parameters should be limited and should clearly reflect the objectives that the government wishes to pursue through allocation.
- Work program bidding is often used to directly affect the quality and level of investment in an area.
- Joint bidding need not imply anti-competitive behavior. Joint-bidding allows companies to share information, infrastructure and especially risk, which experience shows could encourage small companies to enter the auction. In other cases, joint-venturing can also reduce information asymmetries if one of the partners is a dominant pre-existing operator, such as National Oil Company, which may have better information about the prospects of an area. There may also be significant real cost savings available from sharing existing mid-stream infrastructure that is not currently being used to capacity
- The use of area wide licensing or nomination affects bidders' strategies and outcomes as well as the pace of development of the resource base.

- The extent to which different companies specialize in different types of exploration activities and tolerate different risks can be very important to the design of efficient allocation systems.

Hernandez-Perez (2011) collects evidence on the strategies followed by bidding companies in the case of scoring auctions in Brazil. She shows that bids are strongly correlated not only to blocks characteristics such as size, basin and sub-basin location, and previous exploratory record, but also to the oil prices. Once a block is awarded, there is also evidence that exploratory efforts differ by block characteristics.

She also presents evidence of trade-offs across bid dimensions. The bid dimensions in Brazil are the signing bonus, the exploration investment and local content (LC), the later of which is measured as the percentage of goods and services used by bidders that is provided by local companies. Hernandez-Perez (2011) finds that if LC is costly, then companies would be willing to trade upfront bonuses with LC. However, most of the LC only becomes relevant once a field is declared profitable and investment to bring production online begins. A scoring rule that privileges LC instead of upfront payments would, on one hand, decrease the entry barriers in this market and encourage competition among bidding companies, as the capital needs of the winning company are reduced (no need to pay a high bonus upfront). On the other hand, the likely increase in development costs from using higher cost local inputs reduces the likelihood that a field would be developed, as profits must be higher for the field to be commercially viable.

If we consider the introduction of an investment dimension in the bid, having a mandate or a minimum work program may lead to problems of over-investment, given that the risks faced by the companies may not be compensated in expectation by the present value of profits. This is a situation that has been observed in the case of mining industries (Bergstrom, 1984).

There are several considerations regarding the use of lump-sum payments, such as signature bonuses, and the alternative use of taxation. Having non-renewable resources implies also a trade-off between current and future extraction (even if new resources are discovered). This has implications for resource taxes design, including the following:

- The marginal cost to which the marginal benefit from extraction is optimally equated in each period reflects not only the current production cost but the opportunity cost in terms of future extraction foregone.

- A resource stock should be depleted in such a way that the shadow price of the resource (that is, the value of an additional unit of the resource stock) rises at the appropriate risk-adjusted discount rate less a term reflecting the extent to which extraction becomes more costly as the stock declines. The reason for this is simply that deferring extraction will be worthwhile whenever this leads to a gain in future welfare, including through any reduction in future extraction costs, that outweighs the discounting of that future benefit.

The extraction path is entirely unaffected, for instance, if (and only if) the royalty per unit of output rises at the investor's discount rate: for then the present value of the tax payable when some unit of the resource is extracted is the same whenever that extraction takes place. Few royalties are specified to grow in this way, however, so that the extraction path may be affected. For instance, royalty charged as an ad valorem amount (that is, as a proportion of sales receipts) will tend to accelerate extraction if the resource price is expected to increase at a pace above the interest rate.

A more commonly expressed concern with royalties is that they may lead to premature closure of operations: social optimality requires that extraction cease once price no longer covers marginal extraction costs, but private operators faced with a royalty will instead end operations when price ceases to cover extraction cost plus the royalty.

From the above comments, there are several observed block and firm characteristics that could influence the performance of the auction. In addition, including royalties and investment as bid dimensions have several implications. Financially constrained firms could be more willing to enter the auction if royalties are part of the bid, as the payments from royalties are tied to future production. However, this may introduce a distortion relative to the optimal extraction path, depending on the expected oil and gas prices and the interest rate. A higher royalty would also imply a closure of the operation at an earlier date.

Using investment as a bid dimension may increase production in the long run, but may lead to problems of over-investment. In addition, having a large amount of sunk costs after these investments are finished may expose firms to the risk of the government adjusting royalties along the way, which may prevent firms from offering high amounts of investments. In my model, I assume that firms are risk-neutral. Kong (2016), for example, presents evidence that risk aversion is relevant for oil and gas auctions.

To provide a context for the model being used, I proceed to explain some of the institutional features of the oil and gas auctions in Mexico, as well as the considerations by companies at the drilling stage.

3 The auction process for oil and gas leases in Mexico

3.1 Auction stage

As part of the Energy Reform that started in 2013 in Mexico, the government started several auction rounds for oil and gas leases in the country. Several different objectives of the Reform included: increasing knowledge about the oil and gas potential; increasing recovery factors in existing fields; facilitating acquisition of appropriate technology; and promoting the development of exploration and hydrocarbon extraction activities for the benefit of the country, among others.

Given the lack of financial and technological resources by PEMEX, the National Oil Company, allowing private investment through the use of auctions is considered one way of meeting the objectives mentioned above. Other objectives are more relevant than others depending on the type of block being auctioned.

In Mexico, there are three different types of auctioned blocks, according to their location: onshore, shallow water and deepwater fields. Investment in shallow water and deepwater areas is more focused in increasing knowledge about the hydrocarbons potential and acquiring the appropiate technology. In the case of onshore fields, the blocks included in the auction are mature/marginal fields where the amount of resources and the cost of extraction may be attractive to smaller scale low-cost private firms but not to PEMEX. [8] In these fields, investment is probably more focused in increasing recovery rates for fields whose potential has been assessed to a greater extent compared to shallow and deepwater areas.

There are several stages in the auction process: initially the government publishes the auction rules, including the auctioned blocks, the qualifying criteria, and the scoring rule. At that time, companies also decide whether to access the governments geological database on the auctioned blocks. Interested companies must then decide whether to enter as a potential bidder, by meeting financial and technical requirements. The government then publishes the list of potential bidders for that particular round, including individual companies or joint ventures. These bidders can submit an offer for any of the auctioned blocks during a round. On the day of the auction, participants send, in a sealed envelope, their bids for the areas they are interested in. The winner for each block is the firm that has the highest score.

Onshore Areas were auctioned in three different rounds: Round 1.3, Round 2.2 and Round 2.3. In the case of Round 1.3 for onshore areas, conducted in 2015, the score for

[8] Before the start of the auctions allowing private participation, the Mexican government conducted what was called Round Zero where PEMEX indicated in which fields it will continue its operations, a decision that was probably based on the profitability of these fields. The marginal fields considered in the onshore auctions were characterized by low recovery rates, high decline rates and high water percentage, which increase their cost of extraction

bidder i and block j is calculated as:

$$S_i = 0.9 \times (3.5 \times Additional\ royalty_i) + 0.1 \times (2500 \times Additional\ investment_i)^{1/2}$$

where $Additional\ royalty_i$ is the additional percentage offered to the State on the contractual value of hydrocarbons, and $Additional\ investment_i$ is the value of the percentage increase over the Minimum Bidding Work established for each block. This additional investment is measured in work units, and the government establishes a number of work units for different types of works to be performed by winning companies.

In the case of Rounds 2.2 and 2.3, the scoring rule adopted was the following:

$$S_i = Additional\ royalty_i + \left(7.55 \times \frac{Additional\ royalty_i}{100} + 1.33\right) \times Investment\ factor$$

In this case, $Investment\ factor_i$ is a discrete variable, determined by the additional investment commitment if the bidder wins the auction. This additional commitment can only take the following values:

- 1.5 in case that the bidder offers an additional investment commitment equal to the work units required for each block equivalent to two exploratory wells with the corresponding specifications;

- 1 in case that the bidder offers the equivalent to one exploratory well as additional investment commitment;

- 0 in case that the bidder does not offer an additional investment commitment;

Notice that according to the scoring rule in Round 1.3, the marginal effect of a change in the additional royalty on the score is independent on the amount of additional investment being offered, and vice versa. In other words, the additional royalty and the additional royalty are perfect substitutes.

With the new scoring rule, the two dimensions are no longer perfect substitutes and the marginal effect of each dimension on the score depends on the amount offered in the other bid dimension.

In addition, CNH established maximum values on the additional royalty to be offered in the auction.

3.2 The evaluation and development stage

Winning companies sign a contract, which contemplates two stages: an evaluation phase (3 years) and a development phase (25 years after finishing the evaluation phase). During the evaluation phase, companies need to pay a royalty rate that is the sum of the minimum royalty established by law (which is a function of oil prices in the case of onshore fields[9]) and the additional royalty offered in the auction. In addition, companies need to invest a number of work units that is the sum of the minimum work program and the additional investments. The details of their work proposals, including the type of work they will perform to meet the required work units, are sent to CNH for their approval.

If companies do not invest the required work units during the evaluation phase, they have to pay a penalty for the remaining work units, according to a dollar equivalence established by the government.

Companies may decide not to enter the development stage if it's not profitable, which would mean the termination of the contract in the evaluation stage. If they enter the development stage, companies will still pay the minimum royalty rate plus the additional royalty offered.[10] Companies also have to pay a corporate income tax on the profits (established by law at 30%)

Onshore blocks are smaller in terms of area and potential resources if we compare them with shallow water areas or deepwater areas in the Gulf of Mexico. Given that the

[9] Several royalties may be due on production in Mexico, depending on the field's water depth

[10] The Hydrocarbons Law establishes that Mexican company participation in hydrocarbon exploration and extraction activities on Mexican territory must reach at least 35% of the total procurement of goods and services to be used in oil activities in the allocated blocks. Companies are allowed to have a lower percentage at the beginning of the project, and then increase the percentage at later stages of development. This element is not considered in our model

auctioned blocks onshore were initially operated by PEMEX, there is already infrastructure in place to carry on many activities. [11] In addition, there is extensive information on the geology coming from previous drillings. The result less uncertainty to the production forecast compared to shallow water and deepwater areas. where there is less infrastructure and most of the work is focused in exploration. Qualifying financial and technical criteria were lower relative to other types of blocks, in terms of the size of capital of companies or the experience of the operators.

Because of these factors, most of the companies interested in the onshore field auctions were small local companies, some of them created shortly before these auctions were announced. Based on the information revealed by companies to CNH, most of the planned work was related to maintenance and improvement of current operations and gathering additional information about reservoir conditions to have higher recovery factors. [12] Among the tasks commonly performed were the following:[13]

- Well repairs (swabbing, capillary tubing, motor valve replacement, etc.)
- Horizontal or directional drilling of new wells
- Seismic 3D. Dynamic-Static models
- Core sampling
- Other tests (Pressure-Volume-Temperature)

[11] An exception may be that the firm has to provide additional infrastructure to support some types of secondary or tertiary recovery operations

[12] When infrastructure was initially developed, measurement of oil and gas production was not done for each well, but collectively in storage facilities. According to industry experts, this may account for significant changes in measured oil and gas production

[13] Processes related to methods of Enhanced Oil Recovery (EOR) or tertiary recovery operations was not mentioned by winning companies for these blocks. Information from core sampling and other studies may provide an opportunity for these recovery methods in the future. However, for the purposes of this research, we only account for the information from the evaluation plans as the relevant investment.

Among these tasks, the ones that have an immediate impact on production after the evaluation stage are well repairs and the drilling of new wells, whereas the tasks related to gathering information about the field may prove relevant in discovering new resources for the development stage. Even though companies may decide to drill new wells in the development stage or perform other tasks, I only account for the effect of the investments made at the evaluation stage in order to forecast oil and gas production for the rest of the lease.

We also have to consider that the type of work performed depends on the main hydrocarbons that are in the field, that is, whether it is mainly an oil or gas field. This determines the type of technique to be used to increase the recovery of the fluid, and ultimately the impact that investment may have on production. I focus this study in blocks where the main hydrocarbon is oil.

3.3 Data

If we compare the results from Round 1.3 with Rounds 2.2 and 2.3 (see Table 1. Onshore Areas), we notice initially that the number of approved bidders decreased, and the percentage of bidders who were joint-ventures increased. This in turn reduced the number of bidders per auction (from almost 9 in Round 1.3 to less than 2 in Round 2.2 and less than 4 in Round 2.3). It is also importance to notice that the value (in work units) assigned by CNH to a drilled well also more than duplicated after Round 1.3.

Most of the firms participating in the auction were small Mexican companies, with no financial and operational information publicly available. The only information collected relates to the year of creation of the company and the number of employees reported in their LinkedIn page.

As shown in Figure 1, although the number of participating firms decreased, we notice that the average experience of the operating firms for Rounds 2.2 and 2.3 increased. In addition, we notice that the number of firms with less than 200 employees decreased

	Round 1.3	Round 2.2	Round 2.3
# Bidders per auction	10.07	1.9	5.7
# Potential Bidders	40	9	19
# Individual	26	4	11
# Joint-Ventures	14	5	8
Area (Km^2)	24.21	25.3	169.84
Average additional investment (%)	32.42	26.94	34.50
Minimum Investment (*units*)	4,837	5,900	2,942
Well Value (*units*)	4,000	9,400	9,888
Additional Investment (*units*)	2,162	9,400	14,993
Average Reserves Oil Blocks (*mmbbl*)	1.65	0	0.08
Oil price ($US\$/bbl$)	52.32	43.64	43.64

Table 1. Onshore areas.

from 64% to 50%. However, the data imply that firms are relatively small and may have financial constraints that led to joint bids after the change in the scoring rule.

Each winning company has a period of three months after signing the lease contract to make an assessment of how they will use the work units they committed in the auction stage. Evaluation plans are then approved by CNH, and contain information regarding production forecasts and the budget for the 12 months of the evaluation phase. For some of these companies, information about operational costs is available in the approved evaluation plans, but in other cases I believe that only a fraction of the budget is presented as operational cost.

From the observations on the percentage of work units spent by task, we notice that for all blocks where the main hydrocarbon is oil, at least 80% of the units are spent between new wells and well repairs, which are the activities that have immediate impact on production, so that production increases after completing the evaluation phase. This data feature suggests that there is a relationship between the investment committed in

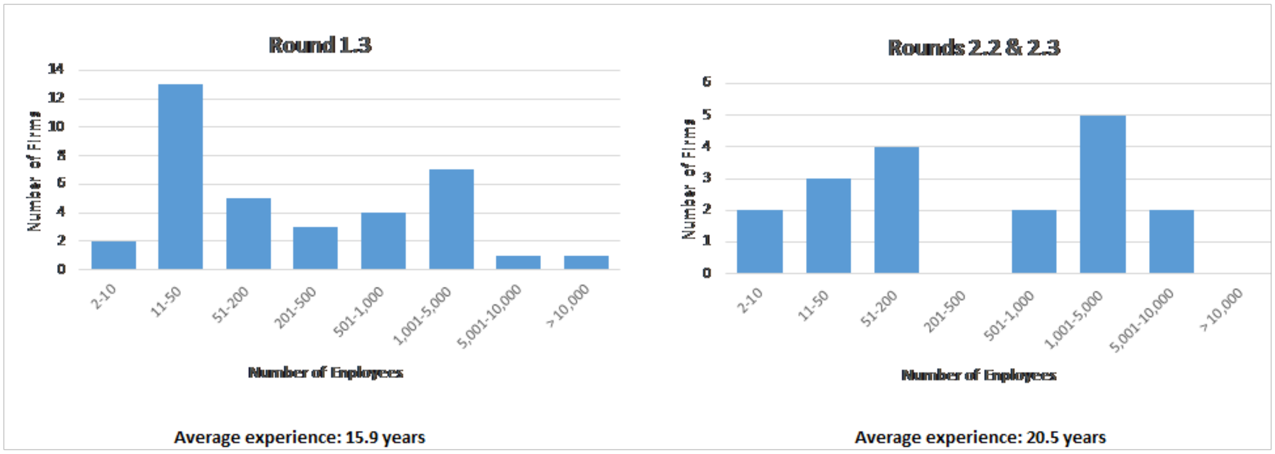

Figure 1: Firms distribution

the auction and the production observed after the evaluation stage.

	Average % Oil
New Wells	69.49
Major well repairs	19.11
Minor well repairs	3.76
Static Models	3.26
Dynamic Models	1.74
Other tasks	2.64

Table 2. Work Units by Task. Evaluation phase. Source: CNH and own estimations

In general, the production forecasts for the winning companies reflect the following: the production by well, once drilled, experiences an exponential decline. The same effect happens

Also, the forecasts suggest (Figure 2) that after completing well repair jobs or drilling wells in a field, there is an initial jump in production, after which production starts declining again.

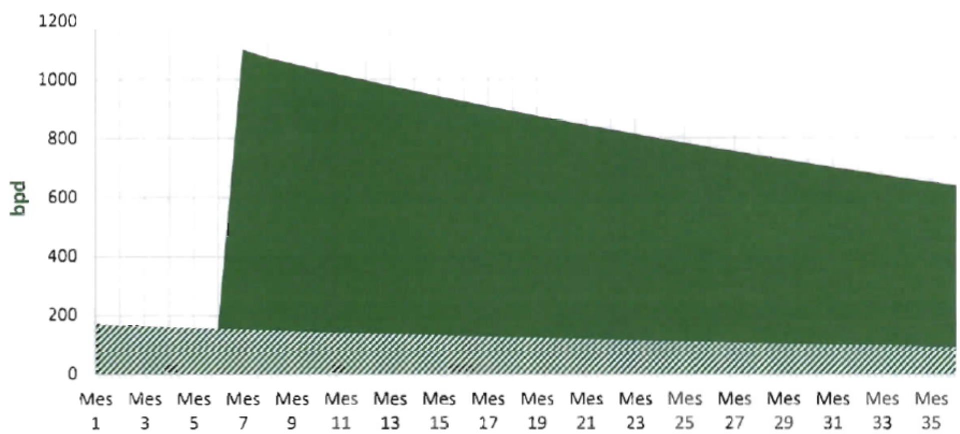

Figure 2: Production profile evaluation plan. Round 1.3. Block 6. Source: CNH

These features suggest that we could think of a jump in production after the investments in the evaluation stage are concluded, that reflects the cumulative effect of the investments over the evaluation phase. The production at the end of the evaluation phase would be the starting point of the development phase, for which production will start to decline at a exponential rate.

3.4 Effects of scoring weights on bid dimensions

From the previous section, it is possible to think that block and firm characteristics can explain part of the variation in bid dimensions. Because the scoring auction may reduce the constraints to the entrance of small firms, we also include the number of competitors in the model. Finally, we include an indicator variable that captures the effect of the change in the scoring rule. With this information I estimate the following model:

$$\begin{aligned}\zeta_{ij} = \beta_1 1[consortium = 1] + \sum_{k=2}^{8} \beta_k 1[Size_{ij} = k] + \beta_9 oilreserves_j + \beta_{10} oilproduction_j \\ + \beta_{11} mwp_j + \beta_{12} area_j + \beta_{13} 1[scrule = 1] + \beta_{14} wellvalue_j\end{aligned}$$

where ζ_{ij} is either the additional investment or the additional royalty offered by bidder i for block j. $oilreserves_j$ are the 2P reserves for block j, $oilproduction_j$ is the cumulative oil production for block j, mwp_j is the amount established by CNH as minimum work program, $wellvalue_j$ is the value established by CNH of a well. The variable $Size_{ij}$ includes dummies for 8 types of firms (0-10,11-50,51-200,201-500,501-1000,1001-5000,5001-10000,$>$ 10000 employees). *scrule* is a variable that is 0 for the original scoring rule and 1 for the new scoring rule (used for rounds 2.2 and 2.3) We use a robust estimator to correct standard errors for heteroskedasticity problems.

In the case of the additional investment, the coefficient is positive, whereas in the case of additional royalties, the coefficient is negative, which suggests a trade-off between both variables. However, results indicate that the change in the scoring rule is not statistically significant to explain the additional investment or the royalties. Individual firm and block characteristics do not seem to be significant either. The value of the well, established by CNH, is the only statistically significant variable explaining changes in both dimensions.

	Estimate	Std. Error	t value	Pr(> |t|)
wellvalue	1.99	.3283	6.08	0.000
scrule	6860.55	4405.91	1.56	0.122
Number of obs = 154				
F(14,139) = 41.98				
Prob > F = 0.0000				
R-squared = 0.8010				

Table 3. Results for Additional Investment. Evaluation phase. Source: CNH and own estimations

Table 4. Results for Additional Investment. Evaluation phase. Source: CNH and own estimations

In this study, we focus on the data from Round 1.3, for which the value of the well

	Estimate	Std. Error	t value	Pr(> |t|)
wellvalue	.001	.0007	2.07	0.04
scrule	-1.4950	9.92	-0.15	0.881
Number of obs = 154				
F(14,139) = 3.61				
Prob > F = 0.0000				
R-squared = 0.1230				

was the same across blocks (at 4000 units), so that we can assess the effects of different scoring rules.

4 Model

Assume there is a set M be a set of $M \geq 2$ bidders, who compete for J tracts in a first-score sealed-bid auction. Before, the auction, each bidder i draws a signal γ_{ij} associated with the marginal cost of performing investment in tract j. This cost is drawn from a distribution H, which is known to all bidders. Assume that γ_{ij} is independent across j and i.

In the auction stage, each bidder i submits a bid for tract j, which consists on two components:

- An additional royalty ϕ_{ij}, which is a percentage added to the royalty established by law $\underline{\phi}(p_t)$ and depends on oil prices.
- An additional investment commitment e_{ij}, which is measured in work units. These investment must be performed in addition to the minimum work program $\underline{e}_j$, established for each tract.

All these components are then used to calculate the score S_{ij}, according to the following formula

$$s_{ij} = 0.9 \times (3.5\phi_{ij}) + 0.1 \times (\sqrt{2500\frac{e_{ij}}{100}}) \tag{1}$$

The bidder who gets the highest score wins the right to develop for a period of T years. Before entering this development stage, companies enter an evaluation stage in which they must invest an amount $\tilde{e}_{ij}$. This amount is equivalent to the sum of the minimum work program and the additional investment:[14]

$$\tilde{e}_{ij} = \underline{e}_j(1 + \frac{e_{ij}}{100}) \tag{2}$$

We will assume there exists a function that describes how production changes with investment $Q : \mathbb{R}_+ \rightarrow \mathbb{R}_+$, with $Q'(.) > 0$ and initially, $Q''(.) < 0$. This function is known to firms before the auction. The previous section showed that there could be different types of work for a specific field. This implies that, theoretically, the same number of work units in two different fields could yield different production increases. We will assume that all companies bidding for the same block will perform the same tasks in the same proportion if they had won the auction. In this way, the differences in $Q()$ will come from the total number of work units invested.

We will assume also that the investment in the evaluation stage determines the initial point for the development stage, and in the development stage production declines exponentially. Therefore, production for firm i at tract j in time t is defined by the following:

$$q_{ijt} = Q(\tilde{e}_{ij})e^{-\alpha_j t} \tag{3}$$

where α_j is a decline rate specific to block j.

During the development stage, firms will sell their production at prices p_t, which are known by firms. Firms will also incur a constant operational cost c_j from oil extraction,

[14] We will assume initially that companies honor their investment commitment instead of paying the penalty.

processing and transport. In addition, during that period, the auction winner will pay the royalty rate $\tilde{\phi}_{ij}$, defined by:

$$\tilde{\phi}_{ij} = \underline{\phi}(p_t) + \phi_{ij} \tag{4}$$

In addition, companies have to pay a corporate income tax τ on the profits. The value ω_{ij} of tract j to bidder i will then be defined in the following way.

$$\omega_{ij} = -\gamma_{ij}\tilde{e}_{ij} + \sum_{t=1}^{T} \beta^t (1-\tau)\Big((1-\tilde{\phi}_{ij})p_t - c_j\Big) Q(\tilde{e}_{ij}) e^{-\alpha_j t} \tag{5}$$

where $\beta^t = \frac{1}{(1+r)^t}$ and r is the interest rate.

5 Identification

The analysis that follows is similar to the one provided by Hanazono et al. (2016) for the more general framework to study scoring auctions. In their setting, the firm with the lowest score is the one that wins the auction, so the discussion of existence and uniqueness is adapted to our framework. My interest in showing the necessary conditions for an equilibrium, in order to show the identification of γ_{ij}. However, I show the conditions under which a unique equilibrium exists, and assume that these conditions hold in this model. A formal proof of the existence and uniqueness of an equilibrium is beyond the scope of this paper. An alternative way of showing identification conditions, assumng a unique equilibrium exists, follows the analysis of Sant'Anna (2017). In the Appendix, I show the equilibrium conditions for my model, using Sant'Anna (2017) analysis.

We initially need to provide technical conditions in our problem that allows us to have an interior solution. First, we have that $S_\phi > 0$ and $S_e > 0$. Moreover, the marginal payoff is inversely related to ϕ, as the winning company has to pay a larger share of revenues with higher ϕ.

Using our knowledge of the scoring rule, we redefine $\tilde{\phi}_{ij}$

$$\tilde{\phi}_{ij} = \underline{\phi}(p_t) + \frac{S_{ij} - 5\sqrt{e_{ij}}}{3.15} \tag{6}$$

The cost of investment function $C(., \gamma)$, and the initial production function $Q(.)$ are differentiable. In order to ensure that the bidder's problem in choosing an optimal e is strictly concave and has an interior solution, we need that the bidder's payoff upon winning is will be non-negative in the case there is no additional investment committed. That is,

$$-\gamma_{ij}\underline{e}_j + \sum_{t=1}^{T} \beta^t (1-\tau)\Big((1 - \underline{\phi}(p_t) - \frac{S_{ij}}{0.9 \times 3.5})p_t - c_j\Big)Q(\tilde{e}_{ij})e^{-\alpha t} > 0 \tag{7}$$

Moreover, for a particular score, we need to check that the bidder's problem in choosing an optimal e_{ij} is strictly concave. For that we need that the marginal payoff eventually decreases, that is

$$-\gamma_{ij}\underline{e}_j + \sum_{t=1}^{T} \beta^t(1-\tau)\Big(\frac{5}{6.3\sqrt{e_{ij}}} p_t Q(\tilde{e}_{ij})e^{-\alpha t} + Q'(\tilde{e}_{ij})\underline{e}_j e^{-\alpha t}\big[(1 - \underline{\phi}(p_t) - \Big(\frac{S_{ij} - 5\sqrt{e_{ij}}}{3.15}\Big))p_t - c_j\big]\Big) \tag{8}$$

to be decreasing in e_{ij}. This condition will imply that the marginal payoff eventually becomes negative as e_{ij} rises.

When having an independent scoring rule, we can express bidder i's problem defined as the following two-step maximization:

$$\max_{s_{ij}} \Big[\max_{\phi_{ij}, e_{ij}} \Big\{ -\gamma_{ij}\tilde{e}_{ij} + \sum_{t=1}^{T} \beta^t(1-\tau)\Big((1-\tilde{\phi}_{ij})p_t - c_j)\Big)Q(\tilde{e}_{ij})e^{-\alpha t} \mid S(\phi_{ij}, e_{ij}) = s_{ij} \Big\}\Big] \Pr[s_{ij} \geq \max_{k \neq i} s_{kj}] \tag{9}$$

In this game, once bidders receive the signal γ_{ij}, they choose a score s_{ij} and given that score, they choose ϕ_{ij} and e_{ij} to maximize profits. The outcome of this game is equivalent to that of the original scoring auction game.

To solve the two-step optimization problem backward, let us first examine the value function of the second-step maximization:

$$u(s_{ij}, \gamma_{ij}) := \max_{\phi_{ij}, e_{ij}} -\gamma_{ij}(\tilde{e}_{ij} + \sum_{t=1}^{T} \beta^t (1-\tau)\Big((1-\tilde{\phi_{ij}}(p_t))p_t - c_j\Big)Q(\tilde{e}_{ij})e^{-\alpha_j t} \tag{10}$$

We call $u()$ the *induced utility function*. It is is the amount of the payment bidder type γ earns when winning. If our assumptions for an interior solution hold, then $u(s, \gamma)$ is well defined. By using $u()$, we can then rewrite bidder i's first-step problems as:

$$\max_{s_{ij}} u(s_{ij}, \gamma_{ij}) \Pr[win \mid s_{ij}] \tag{11}$$

For the second step, given the conditions on function $Q()$ and the linear cost, we can find an interior solution that maximizes $u(s_i, \omega_i, \gamma_i)$ given s_i. First order conditions for e_i (for a given value of s_i) indicate that e_i^* must solve

$$\gamma_{ij}\underline{e}_j = \sum_{t=1}^{T} \beta^t (1-\tau)\Big(\frac{5}{6.3\sqrt{e_{ij}}} p_t Q(\tilde{e}_{ij})e^{-\alpha t} + Q'(\tilde{e}_{ij})\underline{e}_j e^{-\alpha t}\big[(1-\underline{\phi}(p_t) - \Big(\frac{S_{ij} - 5\sqrt{e_{ij}}}{3.15}\Big))p_t - c_j\big]\Big) \tag{12}$$

Let s_{ij}^* and e_{ij}^* be the optimal choices of s_{ij} in the first stage and e_{ij} in the second stage, then ϕ_i^* will be determined by

$$\phi_{ij}^* = \frac{s_{ij}^* - 5\sqrt{e_{ij}^*}}{3.15} \tag{13}$$

To provide an analogy to the firm maximization problem, $\phi_{ij}(s_{ij})$ and $e_{ij}(s_{ij})$ can be thought as "input demand" for a given level of "production" (combinations of ϕ and e that maximize the profit for a given score). The firm then has to choose the "production" (s_{ij}) that maximizes expected profits.

In order to identify γ_{ij} from the observed bids and the information about profits in the development stage, we need to show that there exists an unique equilibrium for the bidder's problem.

To show the existence of an equilibrium, Hanazono et.al (2016) focus on showing that the Single Crossing Condition for games of incomplete information holds.[15] First, suppose that a symmetric pure monotone equilibrium strategy $\sigma_I : \Theta \to \mathbb{S}$ exists, where Θ is the space of cost types and $\mathbb{S}$ is the space for scores. If all bidders play σ_I, then bidder i's equilibrium multidimensional bid in the original First-Score (FS) auction is given by:

$$(\phi_i^*(\gamma_i), e_i^*(\gamma_i)) = \Big(\phi_i\big(\sigma_I(\gamma_i), e_i(\gamma_i)\big), e_i(\gamma_i)\Big) \tag{14}$$

Suppose that all bidders except for i follow σ_I. Let $G(s)$ and $g(s)$ denote the distribution and density of the score by bidder is rival. Then, the problem for bidder i is given by

$$\max_{s_{ij} \in \mathbb{S}} \pi(s_{ij}, \gamma_{ij}) = u(s_{ij}, \gamma_{ij})[G(s_{ij})]^{n-1} \tag{15}$$

where $u(s_i, \omega_i, \gamma_i)$ is defined by (10).

According to McAdams (2003), in order to show the existence of an equilibrium, we would need to show that

$$\frac{\partial^2 \pi}{\partial S_{ij} \partial e_{ij}} \geq 0, \qquad \frac{\partial^2 \pi}{\partial \gamma_{ij} \partial e_{ij}} \geq 0, \qquad \frac{\partial^2 \pi}{\partial S_{ij} \partial \gamma_{ij}} \geq 0$$

In order to derive our identification conditions and estimate our model, we would also have to show that a uniqueness of the equilibrium. Following Hanazono et. al (2016), if

[15] Milgrom and Shannon's (1994) single crossing property refers to a situation by which, when choosing between a low action and a high action, if a low type of player i weakly (strictly) prefers the higher action, then all higher types of agent i weakly (strictly) prefer the higher action as well. Athey (2001) that when a game of incomplete information satisfies the Single Crossing Condition (SCC) and the players are restricted to choose from a finite action set, a Pure Strategy Nash Equilibrium (PSNE) exists. She also shows that if players' utility functions are continuous, a PSNE to the continuum-action game can be found by taking the limit of a sequence of PSNE of finite-action games. The SCC requires that for every player i, whenever each of player i's opponents uses a nondecreasing pure strategy, player i's expected payoffs satisfy . A player's strategy is said to be nondecreasing if it assigns (weakly) higher actions to higher types.

a unique symmetric pure monotone equilibrium strategy exists (call it $\sigma_I^*()$), then it must satisfy the following conditions:

$$\frac{G(\sigma_I^*(\gamma_i))}{(n-1)g(\sigma_I^*(\gamma_i))} = -\frac{u(\sigma_I^*(\gamma_i),(\gamma_i))}{u_s(\sigma_I^*(\gamma_i),(\gamma_i))} \tag{16}$$

$$\gamma_{ij}\underline{e}_j = \sum_{t=1}^{T}\beta^t(1-\tau)\Big(\frac{5}{6.3\sqrt{e_{ij}}}p_tQ(\tilde{e}_{ij})e^{-\alpha t}+Q'(\tilde{e}_{ij})\underline{e}_je^{-\alpha t}\big[\big(1-\underline{\phi}(p_t)-\Big(\frac{S_{ij}-5\sqrt{e_{ij}}}{3.15}\Big)\big)p_t-c_j\big]\Big) \tag{17}$$

where $u_s(.)$ is the partial derivative of $u(.)$ with respect to s (First-step maximization). This is how bidder i chooses s_i.

We need to show first that for a given $G(.)$, $\sigma(.)$ is the unique solution to bidder problem (15). Let us denote by $\theta = \frac{1}{\gamma}$, and $\underline{s} = \min_{\theta\in\Theta} z(\theta)$, the score from which the least efficient bidder obtains zero profits. Assume that G(s) satisfies

- G(s) is strictly increasing and continuously differentiable.
- G($\underline{s}$) = 0

The single crossing property is well known to ensure the pseudoconcavity of the bidder's objective function with respect to s_i. Given the assumption on G(.), expression (16) is sufficient for the unique global maximum.

Then it needs to be shown that G(.) exists uniquely in the following two steps. First, we need to construct a differential equation with respect to G(.) that is consistent with the FOC expressed in (16). Then, we need to show that the differential equation has a unique solution. The FOC implies that all bidders that choose the same score in equilibrium have an identical value of $\frac{u(.)}{u_s(.)}$. For our analysis, we assume that these conditions hold and that an unique equilibrium exists.

Let (ϕ_{ij}^*, e_{ij}^*) denote an observed multidimensional bid, and let s_{ij}^* denote the associated score, given by $s^* = S(\phi, e)$. Suppose that ϕ^* and e^* are generated by equilibrium strategy

$\sigma_I(.)$. Then s^* satisfies the FOC as

$$\frac{G(s^*)}{(n-1)g(s^*)} = -\frac{u(s^*,\gamma)}{u_s(s^*,\gamma)} \tag{18}$$

Using our expression for $u(s^*,\gamma)$, then we can express problem (18) as

$$\begin{aligned}\gamma_{ij}\tilde{e}_{ij}(s_{ij}) = &\sum_{t=1}^{T}\beta^t(1-\tau)\left[\left(1-\underline{\phi}(p_t)\big(\frac{s_{ij}-5\sqrt{e_{ij}(s_{ij})}}{6.3}\big)\right)p_t - c_j\right]Q(\tilde{e}_{ij})e^{-\alpha_j t} \\ &-\frac{1-G(s^*)}{(n-1)g(s^*)}\left[\frac{\gamma_{ij}\underline{e}_j}{100}\frac{de_{ij}(s_{ij})}{ds_{ij}}\sum_{t=1}^{T}\beta^t(1-\tau)\left(\frac{1-\frac{5}{2\sqrt{e_{ij}}}\frac{de_{ij}}{ds_{ij}}}{0.9\times 3.5}\right)\left[\frac{p_tQ(\tilde{e}_{ij})e^{-\alpha_j t}}{3.15}\right]\right]\end{aligned} \tag{19}$$

Moreover, $e^* = e(s^*,\gamma)$ also satisfies

$$\frac{\gamma_{ij}\underline{e}_j}{100} = \sum_{t=1}^{T}\beta^t(1-\tau)\Big(\frac{5}{6.3\sqrt{e_{ij}}}p_tQ(\tilde{e}_{ij})e^{-\alpha t}+Q'(\tilde{e}_{ij})\frac{\underline{e}_j}{100}e^{-\alpha_j t}\big[\big(1-\underline{\phi}(p_t)-\Big(\frac{S_{ij}-5\sqrt{e_{ij}}}{3.15}\Big)\big)p_t-c_j\big]\Big) \tag{20}$$

Given that bidders follow a strictly increasing strategy σ_I, then (19) is increasing in s given e, so there is only one value of γ associated with each s.

For the first-score auction, $G(s)$ and $g(s)$ can be obtained from observations of s^*. The estimates from $Q(\tilde{e})$ can be obtained from observations from production and investment. c_j and α can be estimated using information from evaluation plans of companies for each block j. Companies provide a budget for operational cost either in their evaluation or development plans, which is normalized by the production they expect during that period. As for p_t, we use forecasts for oil and gas prices for the benchmarks considered in the contracts at the moment the auction was held. [16]

6 Estimation

What follows is a multi-step procedure to estimate the model described in the previous section. In the first stage, we need to estimate both $G(s)$ and $g(s)$. For that, we follow a

[16]Forecasts for Brent prices (oil) and Henry Hub (natural gas) come from the Annual Energy Outlook of the U.S. Department of Energy corresponding to the year the auctions were held.

similar procedure to the one discussed by Bajari, Houghton and Tadelis (2014). For the case of our model, we want to incorporate firm and block specific heterogeneity, but given the limited number of observations, we estimate $G(s)$ and $g(s)$ parametrically, running the following regression:

$$s_{ij} = x_i\mu + u_j + \epsilon_{ij} \tag{21}$$

where x_i includes firm-specific variables, u_j includes block-specific characteristics that are observed by the bidders but not the econometrician. Let $\hat{\mu}$ denote the estimated value of μ, $\hat{\theta}$ denote the estimated value of θ and let $\hat{\epsilon}_{ij}$ denote the fitted residual. We assume that the residuals to this regression are i.i.d. with distribution $H(.)$. Under these assumptions, for bidder i and block j

$$\begin{aligned} Pr(s_{ij} \leq s) &= Pr(x_{ij}\mu + u_j + \epsilon_{ij} \leq s) \\ = Pr(\epsilon_{ij} \leq s - x_i\mu - u_j) &= H(s - x_{ij}\mu - u_j) \end{aligned} \tag{22}$$

That is, we estimate $H(.)$ using the distribution of the fitted residuals $\hat{\epsilon}_{ij}$. We recover an estimate of $G(s)$ by substituting in this distribution in place of $H(.)$. An estimate of $g(s)$ can be formed using similar logic.

In order to estimate future production $q_{ijt} = Q(\underline{e}_j + e_{ij})e^{\alpha_j t}$, we need an estimate of the function $Q()$. We try the following functional forms:

$$Q_j = \beta_1(e_j)^{\beta_2} + \upsilon_{j1} \tag{23}$$

$$Q_j = \beta_3 \ln(e_j) + \upsilon_{j2} \tag{24}$$

In this case Q_j is reported in the evaluation plans from the winning company for each block j, as the maximum difference between the total expected production and the "baseline" production in a month. The "baseline" production is reported by each winning company as the production under the scenario they continue the operation without any additional investment.

Since we only see the production forecasts for the winning company, we make the assumption that the production forecasts are similar for any company bidding for the same block (if they were doing the same investment as the winning company), or that $Q_j = q_{ij} \quad \forall \quad i \in N_j$, where N_j is the set of bidders for block j. e_j is the number of investment units made by the winning company in block j

In order to estimate α, we use the production forecasts for twelve months provided by winning companies for each block j, using the following equation:

$$q_{jt} = \eta_1 e^{\alpha_j t} + \zeta_j \tag{25}$$

where q_{jt} is the production forecast at month t by the winning company of block j under the baseline scenario (in which no investment is made). [17] Notice also that an underlying assumption is that companies will be operating for the extent of the lease, and that royalties do not introduce a distortion in the extraction path for companies. We make these assumptions to exclude other decisions at the drilling stage.

Let $\hat{\beta}_1, \hat{\beta}_2, \hat{\alpha}_j$ be the estimates of $\beta_1, \beta_2, \alpha_j$ respectively, then we can estimate $q_{ijt} = \hat{Q}(\underline{e}_j + e^*_{ij})e^{-\hat{\alpha}t}$. With the available data on p_t, c_j, β, and using the estimates $\hat{Q}(\underline{e}_j(1 + e^*_{ij}))e^{-\hat{\alpha}t}$, and the observations on (e_{ij}, s_{ij}), we can generate our moment conditions. From the previous section, we know that γ_{ij} is identified with the available data and estimates.

The model of optimal bidding described in the previous section predicts that the optimal bid solves the first order conditions (19) and (20). These first order conditions are not related to block or firm characteristics

With this, γ_{ij} has to satisfy the following moment conditions:

[17] There were 5 cases (out of 25) in which winning companies did not report production forecasts in the baseline scenario. In those cases, we estimated a weighted average of the decline rate for each of the wells operating in block j, using historical production data by well provided by PEMEX, the National Oil Company

$$E\Bigg\{\Bigg[\sum_{t=1}^{T}\beta^t(1-\tau)\Big(\frac{5}{6.3\sqrt{e_{ij}}}p_tQ(\tilde{e}_{ij})e^{-\alpha t}$$

$$+Q'(\tilde{e}_{ij})\underline{e}_je^{-\alpha t}\big[\big(1-\underline{\phi}(p_t)-\Big(\frac{S_{ij}-5\sqrt{e_{ij}}}{3.15}\Big)\big)p_t-c_j\big]\Big)-\gamma_{ij}\underline{e}_j\Bigg]X_{ij}\Bigg\}=0 \tag{26}$$

$$E\Bigg\{\Bigg[\sum_{t=1}^{T}\beta^t(1-\tau)\Bigg[\Bigg\{\Bigg(1-\underline{\phi}(p_t)-\Big(\frac{s^*_{ij}-5\sqrt{e_{ij}(s^*_{ij})}}{3.15}\Big)\Bigg)p_t-c_j\Bigg\}Q(\underline{e}_j(1+e^*_{ij}(s^*_{ij})))e^{-\alpha t}\Bigg]$$

$$-\gamma_{ij}\big(\underline{e}_j(1+e^*_{ij}(s^*_{ij}))\big)+\frac{1-G(s^*_{ij})}{(n_j-1)g(s^*_{ij})}\sum_{t=1}^{T}\beta^t\Bigg[\frac{p_tQ(\underline{e}_j(1+e^*_{ij}(s^*_{ij})))e^{-\alpha t}}{3.15}\Bigg]\Bigg]X_{ij}\Bigg\}=0 \tag{27}$$

These moment conditions are zero in expectation and not for each individual bid given unobserved block effects that may imply a different initial production to the one predicted by $Q(\tilde{e}_{ij})$.

7 Results

For the purposes of the estimation of $gamma_{ij}$ we consider Round 1.3 to be the our sample, consisting of 14 blocks and 114 individual bids, corresponding to oil blocks. Regarding the functional form for $Q(e_j)$, we estimate both equations (24) and 25 and choose (24), the log specification, as it minimizes both the Akaike Information Criteria and the Bayesian Information criteria. With this specification, using the average of additional investment from the sample will predict a production increase of approximately 1,100 barrels per day.

The next step is to have an estimate for the distribution and density function of the scores $\hat{G}(s)$ and $\hat{g}(s)$, for that we estimate the following model:

$$s_{ij}=\sum_{i=1}^{6}\beta_i size_{ij}+\sum_{j=1}^{14}\beta_ju_j+\epsilon_{ij} \tag{28}$$

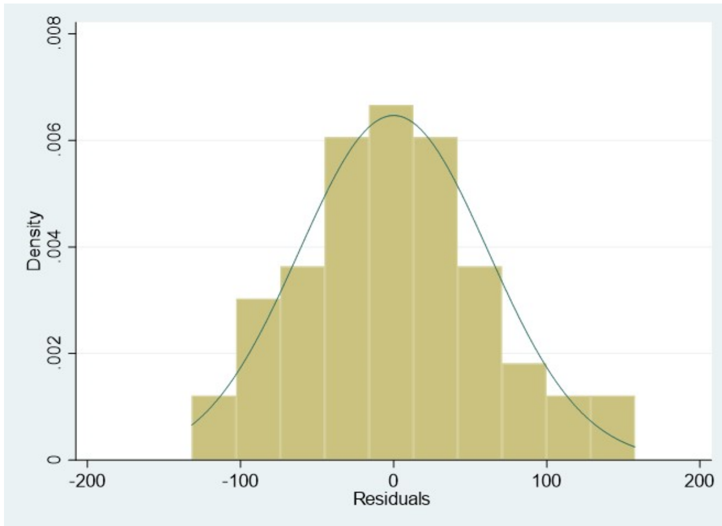

Figure 3: Density residuals

where $size_{ij}$ are dummy variables for different sizes of the firms and u_j is a block specific dummy to capture heterogeneity across blocks.

Results from our estimation indicate that the hypothesis for normality across residuals $\hat{\epsilon}_{ij}$ cannot be rejected

Ho: Normality in Error Distribution	
	LM Test = 1.39260
	DF Chi2 = 2
	Prob. > Chi2 = 0.49843

Table 3. Jarque-Bera test for normality

I use equation (25) to estimate α_j, the decline rate, the weighted average for the sample was of 6.8%, per month, or 43.1% per year. As for the interest rates, 15% was assumed, which came from estimates provided by experts operating in mature onshore fields in Mexico.

The weighted average operating cost per barrel c_j was of \$7.3 per barrel, which is similar to other estimates for onshore marginal fields[18], but with a significant standard deviation of 4.97$ per barrel, which may suggest differences in the reporting of the operational budget and/or the production forecast by companies.

For the price of oil, we use the forecast provided by the Energy Information Administration in their Annual Energy Outlook for the year 2015, when Round 1.3 was held.

Given the data on $\underline{e}_j, e_{ij}, c_j, s_{ij}, \alpha_j$, and the estimates $\hat{q}_t = \hat{Q}(e_{ij})e^{-\hat{\alpha}_j t}$, we can use equation (20) to obtain each individual γ_{ij}. The median γ_{ij} from the sample was of $1,632\$/work\ unit$ and the mean $2,965.71$. Performing an Anderson-Darling goodness of fit test, the distribution that best fits this sample is a Generalized Extreme value distribution, which is the one we use to generate finite samples to use in the counterfactual exercises.

We can also perform a GMM estimation using the moments defined by equations (26) and (27).

Coefficient	2973,99
Std. Error	384.64
95% confidence interval	[2220.108, 3727.871]

Table 4. Results GMM for $\hat{\gamma}$

From this, the estimated value of γ is of $2,974\$/work\ unit$ with a standard error of $384.64\$/work\ unit$. As a reference, the National Hydrocarbons commission in Mexico sets values for work units in the case companies default on their investment commitments, and it is a function of oil prices. The maximum value of this reference work unit is of $1,341\$/work\ unit$. In the case of Brazil, Sant'Anna (2017) found that we cost of the work unit was of $R1081/workunit$ or approximately $400\S/workunit$. With the median estimate in our sample for Mexico, the value of a drilled well is of around $6.5millionUS\$$

[18]http://www.ijsit.com/admin/ijsit_files/PROBABLISTIC$\%$20EVALUATION$\%$20OF$\%$20ONSHORE$\%$20MARGINALOIL$\%$20FIELDS$\%$DEVELOPMENT$\%$20IN$\%$20NIGERIA_IJSIT_6.4.12.pdf

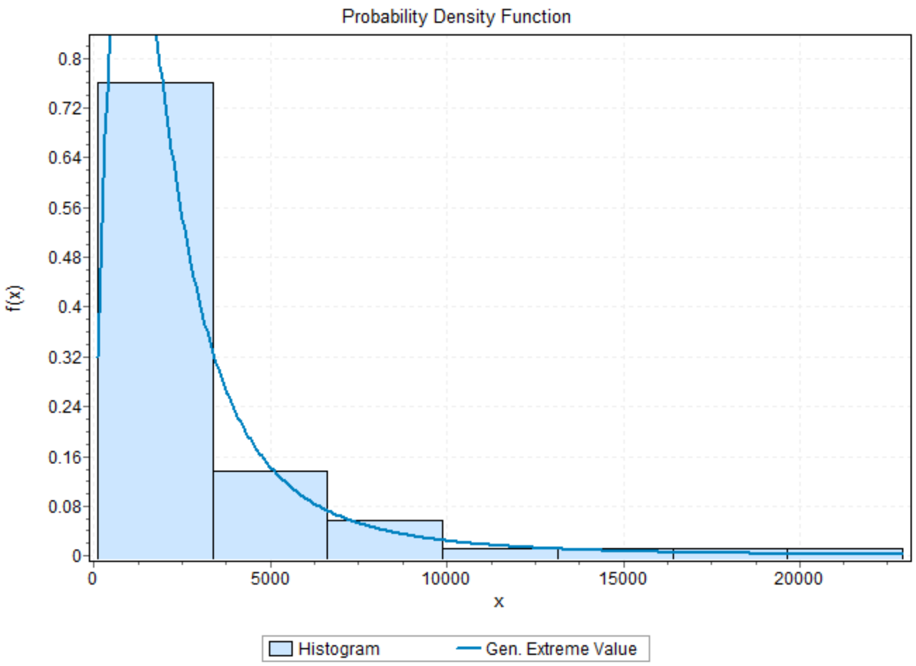

Figure 4: Distribution for the cost of investment

which is in the range of estimates provided by industry experts for an average well [19].

There is reason to believe that our estimates for the cost of investment are higher than the true value of γ, for at least two reasons. First, our profit function does not include other costs other than the operational cost, especially general and administrative expenses involved in the project, which do not depend on production. Second, the oil production forecasts we use are the ones provided by winning companies, which implies that the marginal productivity of the investment may be higher than the average firm bidding for a specific block. Moreover, the estimates provided by winning companies probably were optimistic, in the sense that the production forecast for the evaluation period has been on average about four times as high as the observed production in the same period. [20]Both

[19]The estimates differ depending on the depth of a drilled well, the type of well (directional or vertical), geological characteristics, among other factors

[20]Part of the explanation is that evaluation plans (including production forecasts), have to be provided by companies within three months of taking possession of the block. Operating companies considered this

the absence of administrative expenses and the overestimation of production increase the marginal benefit of investment, and therefore increase the marginal cost of investment, for a given investment level.

8 The effect of changes in the scoring rule

We can use our distribution of γ_{ij} to analyze the effects of changes in the scoring rule. In the case of Mexico, the rule used for Rounds 2.2 and 2.3 involved the use of an investment factor that was based on the number of drilled wells, which is different than the percentage increase in investment that was offered in Round 1.3. In order to perform the comparison, we adopt the following forms for the scoring rule:

$$S_{ij} = 0.9 \times 3.5 \times \phi_{ij} + 0.1 \times 5 \times \sqrt{e_{ij}} \tag{29}$$

$$S_{ij} = \phi_{ij} + \left(7.55 \times \frac{\phi_{ij}}{100} + 1.33\right)\frac{(1+e_{ij})e_j}{4000} \tag{30}$$

We then can sample from our estimated distribution of the cost of investment γ and use equations (19) and (20) to solve for the optimal e^*_{ij} and s^*_{ij}. Then, we can use the scoring rule to solve for ϕ^*_{ij}. Using the data on e_j for Round 1.3, we can estimate the total investment commitment for firms, and using our estimates for the decline rate and our functional form for $Q()$, we can forecast production under both scenarios. This allows us to compare the expected investment and government revenue for both scoring rules.

The second comparison we perform is for a more general form of equation (29), such that

$$S_{ij} = (\zeta) \times 3.5 \times \phi_{ij} + (1-\zeta) \times 5 \times \sqrt{e_{ij}} \tag{31}$$

to be a very short time to provide forecasts, so there may have been an incentive to inflate the production forecast to get approval of the evaluation plan.

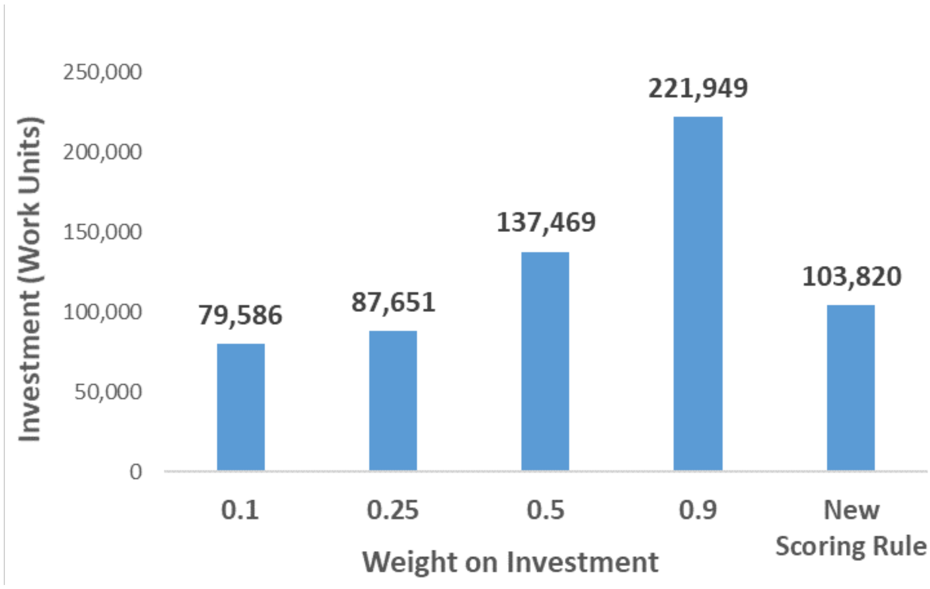

Figure 5: Comparison investment across scoring rules

The idea is to compare what are the effects on government revenue and companies investment for changing weights on the original scoring rule.

Results are referred to the government revenue coming from royalties. Initially, that overall investment is higher when the weight on investment is higher, consistent with the idea of having perfect substitutes under the rule defined by 31. This also implies that production is higher when investment is higher. However, additional royalties are lower as we increase ζ, the weight on investment (from an average of 39.2% when $\zeta = 0.1$ to an average of 17.26% when $\zeta = 0.9$. Therefore, there are two different effects when we increase the weight on investment: higher production but lower royalties per barrel. Initially, the marginal effect of increased investment and production is larger than the effect of the decline in royalty per barrel. This is why government revenue (coming from royalties) increases from \$615.68MM to \$634.32MM. As the weight on investment keeps increasing, the lower marginal productivity of investment implies that the effect of lower royalties per barrel on government revenue becomes larger relative to the effect of increased production. Because of this, government revenue declines to \$429.53 MM

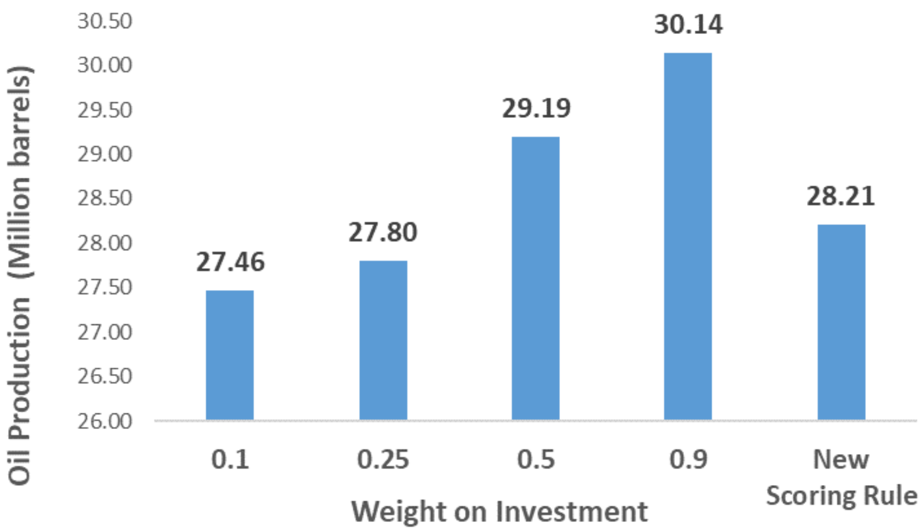

Figure 6: Comparison oil production across scoring rules

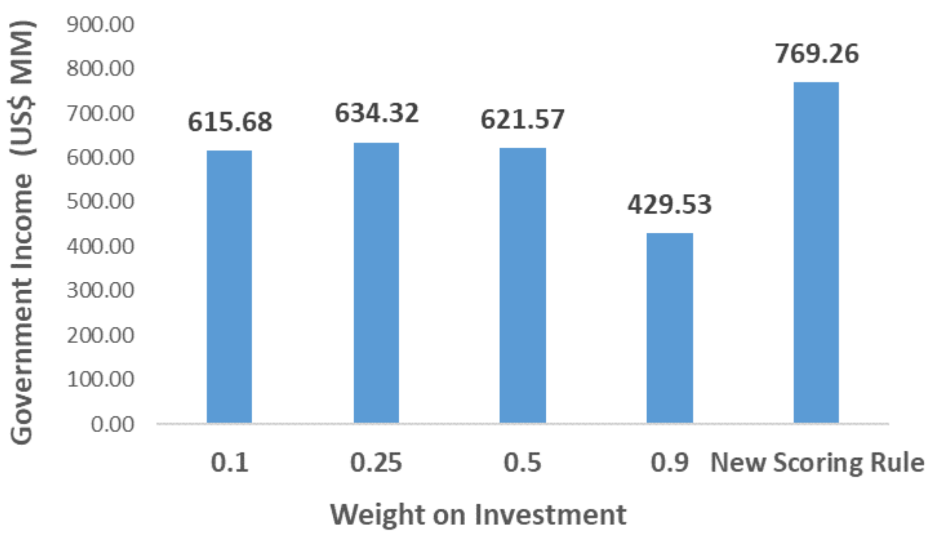

Figure 7: Comparison government revenue (from royalties) across scoring rules

when $\zeta = 0.9$. One question would be why the Mexican the government decided not to have a higher weight on investment. As we discuss in the next section, this may have something to do with the idea that having very low royalties and high sunk costs may provide an opportunity for subsequent administrations to increase taxes once investments are finished, as their bargaining position gets stronger.

When we compare the results with the new scoring rule (used in Rounds 2.2 and 2.3) both additional royalties (not shown, but on average around 60%) and additional investment are larger than under the scoring rule used for Round 1.3. This suggests that having complementary bid dimensions allows for less extreme combinations that increase the tax base.

9 Further questions

Using this framework we can think of several questions that may be of interest to the regulator. In this simple model we assume a given trajectory for oil prices. This framework can also allow for uncertainty in prices. For instance, Bhattacharya, Ordin and Roberts (2018) assume that oil prices follow a Brownian motion, and simulate auction and drilling outcomes for changes in the expected prices and volatility.

We can also look for the different trade-offs between changing weights in the scoring auction or increasing the minimum work program $\underline{e}_j$, and just have a price auction $\zeta = 1$ in our model. The framework could also allow for changes in the corporate income tax, allowing us to evaluate the different tax structures that could be applied. The use of income taxes requires more information about the company relative to the use of royalties, but the use of royalties can introduce distortions.

There is also the question of the use of royalties as a bid dimension, instead of signature bonuses. One interpretation is that when including auctions using fixed payments such as bonuses, or investment commitments, the benefits come in the short-term, and the income for subsequent governments will come from the taxation and the increase in production.

However, given that later there will be a high amount of sunk costs, the incentives may be for other administrations to increase taxes. This may imply that if the weight on the investment component increases, investment by companies may be lower than what the model predicts, as they may risk to pay higher taxes in the future, when the investments are sunk. This also can explain why the CNH decided not to have a higher weight on investment for Round 1.3, even if could increase oil production and possibly government revenues. These questions are related to what is known in the literature as the "hold-up problem", arising from a situation of weak contract enforcement. Ryan (2018) explores a similar problem in the context of procurement auctions for electricity in India, which also uses a scoring auction design. In our model, we assume that firms are risk neutral, but modelling risk aversion can actually have different implications in the way firms choose their bid, in order to account for this problem.

We also need to consider the role of work units and the equivalence established by the government, as it may act as an additional weight in the scoring rule.

The model also provides an opportunity to compare an auction where bid on additional royalties while having a fixed mandate for investment, to a scoring auction. In this way, we can compare the effects of changing the minimum work program in a price auction to what happens in a scoring auction.

10 Concluding remarks

In this study, we use data on auctions for oil leases in Mexico and information about investment plans from winning companies to estimate the distribution of their cost of investment. With this estimates, we assessed the effects of different scoring rules.

Under a scoring rule where bid dimensions are perfect substitutes, a higher weight on investment induces higher investment and production but lower government take (as royalties offered are lower). When the weight on investment is very low, an increase in this component increases government revenues, as the effect of the increase in production is larger than the loss of government take. However, as the weight on investment increases, the government take effect becomes larger and the government revenue coming from royalties decreases.

The scoring rule used in Round 2.2 and 2.3 increases government revenues relative to the one used in Round 1.3. This suggests that using a scoring rule where bid dimensions are complementary may provide combinations of additional royalties and investment that increase the tax base.

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12 Appendix

Another way of setting the first order conditions and the identification of $gamma_{ij}$ follows a similar argument to Sant'Anna (2017).

Let ω_{ij} be defined as in equation (5).

$$\omega_{ij}(\phi_{ij}, e_{ij}) = -\gamma_{ij}\underline{e}_j(1 + e_{ij}) + \sum_{t=1}^{T} \beta^t (1 - \tau)\Big((1 - \underline{\phi}(p_t) - \phi_{ij})p_t - c_j\Big)Q(\tilde{e}_{ij})e^{-\alpha_j t}$$

Instead of thinking about the process in two stages, define $G()$, the distribution of scores, as a function of ϕ and e, so that the bidder's problem can be expressed as:

$$\max_{\phi_{ij}, e_{ij}} \omega_{ij}(\phi_{ij}, e_{ij})\big[G(\phi_{ij}, e_{ij})\big]^{n_j - 1} \tag{32}$$

The first order conditions for ϕ and e are given respectively by:

$$\omega_{ij}(\phi_{ij}, e_{ij}) = \frac{G(\phi_{ij}, e_{ij})}{(n_j - 1)g(\phi_{ij}, e_{ij})} \frac{\frac{\partial \omega_{ij}}{\partial \phi_{ij}}}{\frac{\partial g(\phi_{ij}, e_{ij})}{\partial \phi_{ij}}} \tag{33}$$

$$\omega_{ij}(\phi_{ij}, e_{ij}) = \frac{G(\phi_{ij}, e_{ij})}{(n_j - 1)g(\phi_{ij}, e_{ij})} \frac{\frac{\partial \omega_{ij}}{\partial e_{ij}}}{\frac{\partial g(\phi_{ij}, e_{ij})}{\partial e_{ij}}} \tag{34}$$

where $\frac{\partial g(\phi_{ij}, e_{ij})}{\partial \phi_{ij}}$ and $\frac{\partial g(\phi_{ij}, e_{ij})}{\partial e_{ij}}$ include the marginal effect on the scores of changing ϕ and e, respectively.

This setting has a resemblance to the identification condition in Guerre, Perrigne and Vuong (2000), where the value of the block is a function of the distribution $G()$, the density $g()$ and the number of competitors. In addition, there is an extra term that accounts for the two effects of changing bid dimensions: the effect on ex-post profits, and the effect on the probability of winning (through the effect on scores).

If we assume a parametric form for $G()$, we can proceed in a similar way to section 6 to estimate γ_{ij} from the data on $e_{ij}, \phi_{ij}, p_t, c_j\alpha_j$ and the estimated $Q()$ and $G()$. using either (33) or (34).