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Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Barrientos, Jorge Hugo/Marin, Hector Gomez (2022). Oligopoly and collusion in the Colombian electricity market. In: International Journal of Energy Economics and Policy 12 (3), S. 125 - 134.
https://econjournals.com/index.php/ijeep/article/download/12883/6743/30331.
doi:10.32479/ijeep.12883.

This Version is available at:
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International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2022, 12(3), 125-134.

Oligopoly and Collusion in the Colombian Electricity Market

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Received: 02 January 2022 **Accepted:** 07 April 2022 **DOI:** https://doi.org/10.32479/ijeep.12883

ABSTRACT

The Wholesale Electricity Market –WEM– in Colombia was created with Laws 142 and 143 of 1994 with the aim of promoting and preserving competition among agents and guaranteeing an efficient energy spot price. However, in practice the market works as an oligopoly in competition; evidence indicates there is market concentration, without reaching abuse of dominant position or price collusion, at least not explicitly. This paper develops a game model with incomplete information, in which there is at least a Perfect Bayesian Equilibrium with implicit collusion among agents. That is, it is highly likely that, under certain conditions, some generators tacitly follow the price strategies of agents with greater installed generation capacity (pivotal) and hence propose similar bid prices. The empirical analysis shows that scenarios of radical and similar increases in bid prices, for different generators, are a pattern present in the WEM.

Keywords: Electricity Markets, Oligopoly, Collusion, Incomplete Information, Bayesian Equilibrium
JEL Classifications: C70, C72, D43, D82, L13, L94, Q41

1. INTRODUCTION

With the enactment of Law 142 of 1994, and more specifically Law 143 of 1994 (Colombian Electricity Law), the Energy and Gas Regulatory Commission (CREG, for its name in Spanish) was granted by the Colombian Congress the power to regulate the provision of public utilities, including energy service; it also forced vertically integrated firms to separate their functions from the electricity production chain in order to promote competition and encourage greater participation of the private sector. Within the framework of the law, the Colombian State was seeking to meet demand for electricity guided by the economic criteria of financial viability and efficiency (Congreso de Colombia, 1994a, 1994b). A complete analysis and evaluation of the evolution of the deregulated market for electricity in Colombia since 1995 up to 2002, can be found in Larsen et al. (2004). The Wholesale Electricity Market (WEM) is currently made up of an oligopolistic structure with significant concentration rates in the activity, thus limiting efficiency to a certain extent. In Colombia, there are 16,998 MW of installed generation capacity, 60 % of which is concentrated in four firms with multiple plants.

Given the structure of the Colombian electricity market and the presence of important agents in terms of installed power capacity, it is possible to identify factors that could favor strategic behaviors in prices. First, there is a degree of contraction in the generation market which would allow companies to take advantage of their dominant position and benefit from greater consumer surpluses. Second, there is no rule in the regulation requiring generators to declare their variable costs, facilitating to some extent the manipulation of the spot price of electricity in the pool. Third, constraints in the electric grid become an additional factor as it would encourage generation companies to abuse their dominant position, negatively affecting end users because (i) it can induce generation companies to "withhold" output and lead to a short-term supply shortage, and (ii) it distorts the trading signal of spot prices, resulting in inefficient energy dispatch and investment decisions (Twomey et al., 2005). Investigating whether there are indeed any conditions in the electricity market for the occurrence of collusion among agents is therefore relevant and justified for the above reasons.

This article aims to apply an incomplete information game to analyze the strategic behavior of generators and establish under which conditions could any type of price collusion exist on the spot market in a way that serves as an instrument for the regulator to design monitoring and control mechanisms. The analysis is divided into a theoretical section and an empirical section. First, an analysis of generation companies' strategic behavior is conducted based on the highest possible bid made on the electricity market, where there are agents who may be pivotal, according to a probability distribution assigned by nature. These types of agents send a message informing their bid prices and the receiving agents choose a strategy for bidding once they are aware of said prices. The perfect (or signaling) Bayesian equilibria are thus characterized, and it is established under what information conditions there are identical or similar bid prices for different generators. Second, the results of the equilibria are contrasted with price information from the market, and it is determined whether there are any signals among participants in the electricity market enabling them to make strategic decisions when bidding and tacitly act for the collective benefit.

In the Colombian case, as it is in several countries, the energy spot price is calculated hourly through a sealed-bid auction process, which makes the process an incomplete information game, as each agent is unaware of the assessment that the remaining players have made of the energy bid. A supply curve is constructed by sorting the bids from the generation plants from lowest to highest value; the bid of the plant that reaches equilibrium with demand is the one that sets the Highest Bid Price (HBP) - spot price from now on-. All the generation plants required to supply the demand are remunerated according to the spot price. The spot price and the plants' remuneration are directly affected by variations in the generation plants' bids, so it is important to analyze the generators' bidding strategy.

There are different modelling methods for the power plants' bidding strategies. Gong et al. (2011) carry out a literature review and classify the models into four groups: (i) Generation companies' optimization models, (ii) game theory-based models, (iii) agent-based models (ABM), and (iv) hybrid or other models. Figure 1 shows the modelling methods for bidding energy in the spot market according to Gong et al. (2011). The group of optimization models includes programming methods such as Mixed-Integer Programming (MIP), Dynamic Programming (DP), Markov decision processes (MDP) and Nonlinear Programming (NLP). The group of agent-based models can be categorized in terms of algorithms, including model-based adaptation algorithms (MA), genetic algorithms (GA), automatic reinforcement leaning –Q-Learning (QL)–, computational learning (CL) and Ant Colony Optimization (ACO). Finally, the group of game theory-based models, the focal point of this article, includes Bertrand competition, Cournot competition and Supply Function Equilibrium (SFE).

This article will analyse generation companies' bidding behaviour under the application of a game theory model given that it provides an analytical rationale and an explanation regarding how market power can be exercised through bidding strategies (Gao and Shebleb, 2010). In their work, authors such as Federico and Rahman (2003), Hu (2010), Hobbs (2011), Willems (2002), Ahn and Niemeyer (2007), Park et al. (2001), Kleemperer and Meyer (1989), Niu (2005), Genc and Reynolds (2011), Liu et al. (2010) have modelled generators' bidding strategies based on game theory.

A distinction needs to be drawn between explicit and tacit collusion: the legal implications and economic results are completely different (Martin, 2006). They differ because the former pertains to deals that are deliberately struck among market participants while the latter relates to structural market models leading to conditions in which seemingly there is an agreement among agents yet no such explicit agreement has taken place; this usually occurs because of the accumulated knowledge they have of the structure and operation of the market. This means that, in the case of tacit collusive behaviours, generation companies' bidding strategy must be modelled as a non-cooperative, perfect information game.

As evidenced in the literature review, some authors have modelled electricity markets under different game types; for example, Lucas and Taylor (1993), Lucas and Taylor (1995), Ferrero et al. (1998), Baldick (2002), Kleemperer and Meyer (1989), Green and Newbery (1992), Contreras et al. (2002), Contreras et al. (2004a, 2004b), Correia (2005), Li and Shahidehpour (2005), Hobbs et al. (2000) and Hobbs et al. (2001), who have proposed several models based on non-cooperative games under different information structure schemes applied to electricity markets.

Papers relating to the aim of this study include Ramírez (2008), who seeks to implement a model that allows finding cooperation alternatives among marketing companies to optimize their profits; the author proposes a dynamic game with multiple participants which is solved using a computational method. Rojas (2016) proposes a repeated game using information from certain market variables, namely real demand, spot price, declared availability and price bid. Additionally, the author performs an extensive simulation of profits for eight generation plants in the Colombian market to find the Nash equilibrium of a game in an extensive way and analyses the differences between a static and a dynamic game. In turn, Franco (2012) determines the Nash-Cournot equilibrium using the Nikaido-Isoda relaxation algorithm (NIRA), which makes it possible to convert the equilibrium problem into an optimization one; however, the fact that the electricity market in Colombia is based on price competition (Bertrand) as opposed to quantity competition (Cournot) must be considered in this work.

There is significant literature on concentration and market power in the electricity market, *e.g.*, studies carried out by the market regulator of the United States of America (Federal Energy Regulatory Commission, 2006), Lin and Magnano (2017) and Pérez- Arriaga (2005), who point out there are some indicators to measure market concentration. The most popular include (i) the Herfindahl Hirschman Index (IHH), which indicates the market share each company has but does not provide any information on the actual potential of agents to modify prices; (ii) the Pivotal Supplier Index (PSI), which assesses the number of hours during a time period when a generator was vital for meeting the demand, even though it does not inform about the actual potential of agents to modify prices either; (iii) the Residual Supply Index (RSI), which measures whether an agent is vital for meeting demand when the agent's supply is greater than its residual demand. According to the Colombian regulator CREG (2010), the RSI is considered the best model for determining *ex ante* market power in Colombia.

2. METHODOLOGY

This work proposes a simple game containing the WEM characteristics but at the same time allowing to identify the generation companies' strategies. In principle, it is considered that the market manager will define the spot price of energy and the dispatch of the generation plants based on economic efficiency criteria. In the same way, the game must reflect the oligopolistic competition in prices. Additionally, this is considered an incomplete information game because each agent does not know the bids from the other competitors; they only know their own bid and do not know what type of competitor the others are.

The electricity market is modeled as a two-player (two generation plants) signaling game, in which there is a probability that one player can be a pivotal agent. The latter is based on the fact that the electricity market has oligopolistic characteristics and a large part of the installed capacity in Colombia is concentrated in a few generation companies, providing market power to those agents with greater installed generation capacity. In the proposed signaling model, the agent that can acquire pivotal condition will be the Sender (Player 1), since its dominant position would allow it to establish the energy exchange process and give signals of the condition of the game to the market.

The pivotality characteristic allows the agent to act in two ways to make use of market power: (i) Increase the supply price because demand will pay for the energy at any price, increasing the generator's profit, and (ii) decrease its generation capacity, in such a way that it is required to look for more expensive generation alternatives to supply the demand, implying an increase in the spot price, from which the same generator that restricted the energy will benefit. In both cases, what is finally altered is the energy spot price, and therefore it is assumed that the agent that establishes the price in the pool is the pivotal agent. The pivotal condition is defined by nature with a probability ρ. The Receiver (Player 2) is an agent who has no market power, but who must decide its bidding strategy to ensure a profit.

In the proposed game, the players' strategies are: To bid the marginal cost or to bid another price. As it is assumed that agents are economically rational and have monotonically increasing preferences, it is defined that the Marginal Cost will always be lower than the other price the agent can bid. Consequently, as the electricity market price is determined based on the bid prices, then, increases in bids make the value of electricity in the pool more expensive. The extensive form of the signaling game is represented in Figure 2, where the following can be observed:

- Player 1 is the one who determines the spot price as long as it is pivotal
- When a pivotal condition exists and Player 2 alters its bid price, exceeding the price bid from Player 1, it will not make a profit
- When there is no pivotal condition and players bid at a price above their marginal cost, it is assumed that these agents will not be dispatched and the market manager will choose other more competitive players to meet the demand. Consequently, the profit would be null for the player who alters its price.
- When there is no pivotal condition, and the players bid at a price equivalent to the marginal cost, it is assumed that the

Figure 1: Modelling methods of bidding in the electricity spot market. Taken from Gong (2011)

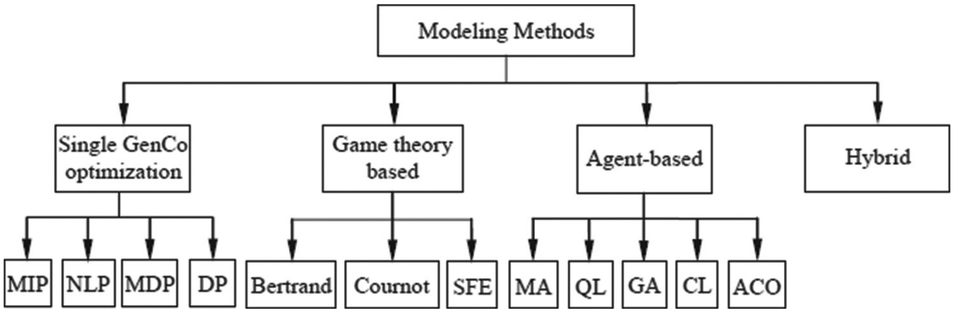
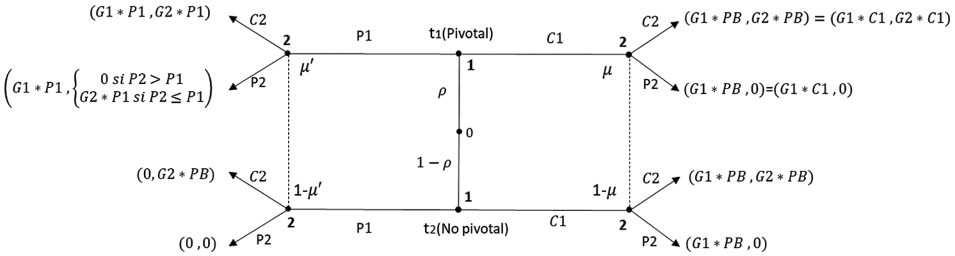


Figure 2: Signaling game



market manager dispatches these players to meet the demand; therefore, the benefit corresponds to the product between the energy dispatched in the pool of each player and the spot price.

where: 1: Generating agent 1; 2: Generating agent 2, C1: Marginal cost of player 1; C2: Marginal cost of player 2; P1: Another price of player 1; P2: Another Price of player 2; SP: Spot price; G1: Generation dispatched in the market of player 1; G2: Generation dispatched in the market of player 2; ρ: Probability that the player is not a pivotal agent [0,1]; (μ,1–μ) and (μ',1–μ') are the beliefs patterns of player 2.

The payments that each player will receive for each one of the strategy profiles are observed in Figure 2. Payment in the electricity market corresponds to the product between the energy generation dispatched and the spot price (for agents that do not trade electricity by forward contracts). For the cases in which the agent is pivotal, it is supposed that the spot price will be at least the pivotal player's bid. Additionally, it is assumed that when one of the players bids a high price (Pi) and there is no pivotal condition, the player is not competitive within the auction mechanism and will not have energy dispatched, and hence will not receive payment in the pool. Based on the above, it is then supposed: $C1 \leq PB \leq P1$ and $C2 \leq PB \leq P2$.

2.1. Perfect Bayesian Equilibria

It should be noted there are no grouping equilibria in this game, and there is only a separating equilibrium, which takes the following form:

Separation with player 1 [$P1$; $C1$]
Let message be $P1$ when the type of player 1 is pivotal, and $C1$ when its type is equal to Non pivotal. For $\rho=0.5$ and supposing there is an equilibrium under these conditions, then we have:

$S_1\ (t_1)=P1 \rightarrow S_2\ (P1)=C2$ supported by the belief pattern $\mu'=1$ and $P2>P1$

Player 2 does not identify the node in which it is located but makes the beliefs that $\mu'=1$. Emphasis is made on the case when $P2>P1$, since player 2 would obtain a payment of $G2^*P1>0$ when choosing action $C2$. Likewise, the case for which player 1 will make the decision of choosing strategy $C1$ is observed. Under this scenario, $C2$ would also be the optimal choice for player 2 since $G2^*C1>0$.

$S_1\ (t_2)=C1 \rightarrow S_2\ (C1)=C2$ supported by the belief pattern $\mu=0$

Player 2 chooses $C2$ because the profit is greater than the one action $P2$ would yield because $G2^*PB>0$. Likewise, if the case is evaluated in which player 1 diverted and chose strategy $P1$, strategy $C2$ of player 2 would still be providing a greater benefit:

$S_1\ (t_1)=P1 \rightarrow S_2\ (P1)=C2$ or $P2$ supported by the belief pattern

$\mu'=1$ and $P2 \leq P1$

In this case, player 2 action would be indifferent since the gain when player 1 chooses $P1$ is the same as if it chose $C2$, which corresponds to $G2^*P1$. This indicates that under this condition player 2 would always choose action $C2$ with probability $\mu'=1$, $\mu=0$, $P2>P1$ and $P2 \leq P1$ or would also choose action $P2$ with probability $\mu'=1$, $\mu=0$ and $P2 \leq P1$. But to find out if player 1 really wants to choose message [$P1$, $C1$], it is observed how player 2 would react toward strategy $C1$ of the t_1 type: the optimal response of player 2 would be $C2$, which would imply that player 1 obtains a payment of $G1^*C1<G1^*P1$ when, being pivotal, it chooses $P1$. In this way it is determined that player 1 effectively prefers to choose strategy $P1$ when it is of pivotal type.

Likewise, it is analyzed how player 2 would react to strategy $P1$ of type t_2 (*Non pivotal*): the optimal answer of player 2 would be also $C2$ and player 1 would obtain a payment of $0<G1^*PB$ when, being non pivotal, it chooses $C1$. In this way it is determined that player 1 effectively prefers to choose strategy $C1$ when it is of non-pivotal type. It can then be claimed that for strategy [$P1$, $C1$] of player 1, there is a separation PBE defined as $S^*=\{S_1^*;S_2^*\}=\{[P1;C1];[P2;C2]\}$ such that $(\mu^*, 1-\mu^*)=(0,1),(\mu'^*,1-\mu'^*)=(1,0)$ for $P2 \leq P1$.

2.2. Perfect Bayesian Equilibrium: A Discussion

The optimal strategy of player 1 in the participation of the electricity market corresponds to increasing its bid price when the player is able to identify that it is a necessary agent for the system (pivotal agent), ratifying the vulnerability of the electricity market to the existence of a pivotal agent within the market. On the other hand, in a market where there are no pivotal players, they will tend to bid their marginal cost to guarantee an income through the energy exchange. The latter underpins the need for the regulator to propose mechanisms that protect demand in the face of possible variations in energy prices in an oligopolistic market where there may be pivotality on the part of a generation company.

As for optimal strategies of player 2 (representative market agent); [$C2$; $C2$] if $P2>P1$ and [$P2$;$C2$] if $P2 \leq P1$, it is observed from the conditionals that the bids from both players tend to be the same. Player 1 will know in the future the bids from the other players, allowing it to make decisions to continue increasing the prices or to adjust them so that it can receive greater benefits without generating alarms by abrupt increases in bid prices. This also benefits player 2, who will be remunerated at the price established by player 1, generating an incentive to bid similarly to avoid wide gaps between the different bids that alert the surveillance and control bodies. In this way the model shows that in an oligopolistic energy market with presence of pivotality there is implicit or tacit collusion. On the other hand, it also reaffirms that, although the energy market optimizes the dispatch of generation plants with reliability, security and economy criteria, the prices are not efficient for the demand. The above allows to conclude that the signaling model proposed represents in a practical way the behavior of the energy market with oligopolistic characteristics and at the same time, the model allows to determine if the agents' strategy reflects an implicit collusive behavior, which could be contrasted with real data.

3. RESULTS

The model does not allow identifying the existence of market power abuse; however, the identified balance shows that an incentive to do so coexists and is possibly complex to identify due to the fact that agents' bids tend not to move away from each other. In the empirical evaluation of the model with actual system data, the consistency of the model with the observed data is reviewed and the possible abuse of market power is questioned. Such comparison is carried out in the following steps: (a) Identifying the dates where pivotality condition occurs; (b) selecting the representative agents to evaluate the signaling game (player 1 and player 2); (c) choosing an analysis scenario (dates) where pivotality occurs and does not occur; (d) evaluating the model using the values of variables belonging to the representative agents in each scenario. To do this, a comparison is made between the PBE obtained theoretically and the payment value for each strategy.

The information that will be used to test the model is taken from the databases of the XM Company Administrator (www.xm.com.co) electricity market operator. As the data from the Colombian energy market is at an hourly level, the work uses variables measured in this time range. Prices are measured in Colombian pesos per kilowatt-hour –\$/kWh–, energy values in Colombian pesos (\$) and energy magnitudes in kilowatt-hour –kWh–d.

3.1. Identifying Dates Where Pivotal Condition Occurs

In order to identify the pivotal scenarios that have taken place in the Colombian market, a methodology proposed by the Colombian regulator is used to determine the Residual Supply Index (RSI). It has been recognized as the most accurate mechanism to determine market power as indicated by the regulator itself in its state of the art, arguing that the mechanism allows to include bilateral contracts in the measurement of market power and to know the limits up to which competition can be exercised. The RSI is determined by the following equation:

$$RSI_{agent,hour} = \frac{X_{hour} - \left(Y_{agent,hour} - C_{agent,hour}\right)}{SD_{hour}}$$

where X: Total system availability, Y: Agent availability, C: *Agent contracts*, SD: System demand

Additionally, the regulator defined that if the RSI is <1.19, it is determined that the agent has pivotal condition and can perform joint strategies to set a spot price higher than the marginal cost (CREG, 2010). Table 1 summarizes the number of days where pivotality condition occurred between January and September 2019.

3.2. Selecting Representative Agents to Evaluate in the Signaling Game

From the results obtained from the RSI, it is evaluated which are the agents that, during the period of time reviewed, were the most likely to have pivotal condition (Table 2). These agents will make up the group of companies that represent player 1 of the designed signaling game. Player 2 can be any company; the model must respond according to the type of player.

Table 1: Days with possible market power between January and September 2019

Evaluated date range	N° of days with NO pivotal agents	N° of days with pivotal agents	Total days
01 January 2019 through 20 September 2019	126	137	263

Source: Own calculations

3.3. Choosing the Analysis Scenario (Dates) Where Pivotality Occurs and Does Not Occur

Initially, it is analyzed whether there is indeed possible market power in the Colombian market. A comparison is made, period by period, between the HBP and the RSI of the two dominant agents. In Figure 3 it can be observed that in January 2019, when there is a low RSI value, the HBP in Colombia tends to rise and vice versa. This shows that when there is greater market power, generation plants increase their supply, obtaining higher HBP values in the market.

However, the above cannot guarantee the existence of market power abuse; it can only be said that in periods of high demand and high prices, market power is most likely to be exercised. To corroborate whether there is some kind of collusive strategy or increases in bids (Marginal Cost), the bidding behavior of the companies under condition of pivotality and no pivotality in short periods of time must be analyzed. In the long term, factors that effectively justify bid variability can occur.

Since bids on the electricity market are made per generation plant, it can be seen graphically that for companies with greater market power, their strategy seems to be based on increasing the price of one plant and decreasing that of another (Figures 4 and 5), in such a way that the average price offered aggregated per company tends to be stable. However, since the price of energy on the market is established by only one offer, if the bid of only one plant of a pivotal agent is high, this is a sufficient condition for the energy price to increase and for the rest of the plants dispatched to receive a higher income.

For this reason, in order to evaluate a possible collusive behavior or market power abuse, as well as to contrast the proposed signaling game, an independent analysis for each day and each plant of the pivotal agents must be made. In accordance with the above, some days in 2019 where pivotality occurs and others where it does not, are chosen to evaluate different study cases.

Days with pivotality condition (2019):
- February 14, 15 and 19
- March 27 and 28
- May 06, 07 and 08.

Days without pivotality condition (2019):
- January 20
- March 24
- April 28

Table 2: Pivotal agents between January and September 2019

01 January 2019 through 20 September 2019		
Company	**N° of periods in pivotal condition**	**N° of days in pivotal condition**
EPM	555	107
EMGESA	527	118
ISAGEN	234	88

Source: Own calculations

Figure 3: HBP versus RSI for January 2019

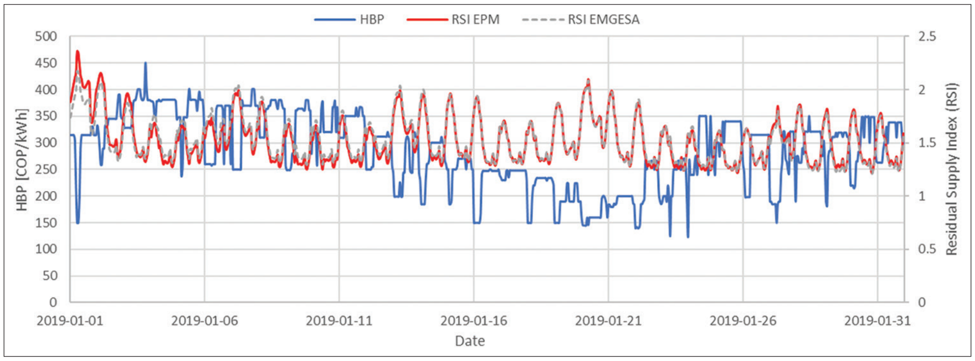


Figure 4: EPM supply prices of January 2019

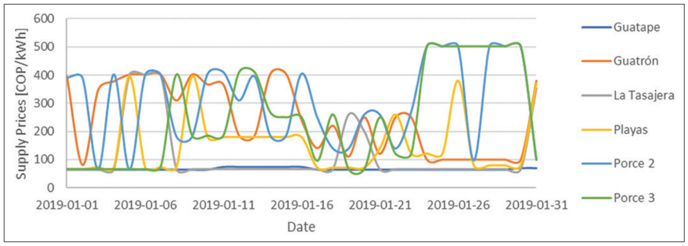
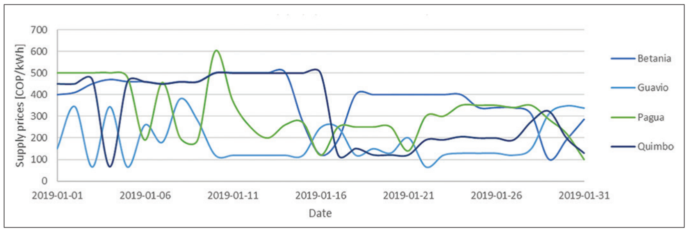


Figure 5: EMGESA supply prices of January2019



- May 30
- June 16

3.4. Evaluating the Signaling Game

3.4.1. Scenario under pivotal conditions: February 14, 15 and 19 of 2019

The RSI is <1.19, especially in periods 20 and 21 for EPM and EMGESA agents. Table 3 shows the HBP for the above periods, highlighting the price of February 15 as one of the highest HBPs during 2019.

The HBP of day 14 corresponds to the same value offered by the Porce 3 and Guavio power generation plants; the former belongs to the EPM agent and the latter to EMGESA, corroborating the fact that a pivotal agent imposes the market price and that different agents report the same or similar prices under pivotal condition. Likewise, the HBP for period 20 of day15 is equal to the bid from the Porce 2 plant owned by EPM, and the HBP for period 20 of day 19 is equal to the bid from the Porce 3 plant, also owned by EPM. The presence of equal bids from different companies is questionable, considering that bid prices in this case were higher than the minimum costs that must be included in the bid by regulation.

Table 3: HBP for February 2019

	HBP (COP/kWh)		
Period	**14 February**	**15 February**	**19 February**
13	296.03	380.03	450.03
20	296.03	510.03	392.03
21	296.03	450.03	379.03

Source: Own calculations

Table 4 contains variations in bid prices of some of the generation plants of both agents with respect to the value offered the previous day. It can be seen that since day 14, the Porce 2 plant increased its bid price by more than 320% with respect to the previous day and maintained it during the following 3 days in which there was a pivotal condition, because later on day 18, EPM's RSI was greater than 1.18; there was no certain pivotal condition, and a 87.2% decrease in the bid was observed.

On the other hand, on day 14, the Guavio plant was marginalized, increasing its bid price by 64% with respect to the previous day's bid and then decreasing it by 78% for the following day. The sharp increases and decreases in bid prices between 1 day and the next, during the days when there is a condition of pivotality, question whether the bid strategy of the dominant companies is due to real changes in the water opportunity cost (or fuel used) or whether the companies are actually altering their prices in a favorable manner. Situations like this are observed for the other days analyzed when there is pivotal condition.

For day 19, there is again pivotal condition for EPM and EMGESA. A 610% increase in the bid price from the Porce 2 plant is evidenced. However, the highest HBP for that day was set by the Quimbo plant of EMGESA in period 13, which had raised its bid price since February 18 by 73% with respect to the price offered the previous day (Table 4). It is also evidenced that, for several periods, the HBP was set by the Porce 3 plant of EPM, which raised its bid price by 3.16% for that day.

In order to evaluate if bidding strategies comply with the PBE determined in the signaling game, a characterization of the game is made with real market information and some assumptions. For this purpose, the previous information is considered, and the players are established. EPM plants are defined as "player 1" and Urra's plant of Urra company as "player 2." The information required to contrast the signaling game is summarized in Table 5. Additionally, since there is no real information on the production cost for each of the agents, the analysis is carried out assuming a

Table 4: Bid price variations in February 2019 for EPM and EMGESA

Date	EPM bids			EPM bid variation (%)			EMGESA bids			EMGESA bid variation (%)		
	Porce 2	Porce 3	Playas	Porce 2	Porce 3	Playas	Guavio	Pagua	Quimbo	Guavio	Pagua	Quimbo
February 11, 2019	429.03	70.94	231.03	0.0	0.0	0.0	220.03	260.03	140.03	0.0	0.0	0.0
February 12, 2019	429.03	271.03	191.03	0.0	282.0	–17.3	245.03	255.03	145.03	11.4	–1.9	3.6
February 13, 2019	120.03	296.03	172.03	–72.0	9.2	–9.9	180.03	235.03	150.03	–26.5	–7.8	3.4
February 14, 2019	510.03	296.03	172.03	324.9	0.0	0.0	296.03	100.03	100.03	64.4	–57.4	–33.3
February 15, 2019	510.03	380.03	161.03	0.0	28.4	–6.4	64.99	64.99	231.03	–78.0	–35.0	131.0
February 16, 2019	510.03	380.03	124.03	0.0	0.0	–23.0	179.59	64.99	230.03	176.3	0.0	–0.4
February 17, 2019	510.03	380.03	124.03	0.0	0.0	0.0	245.74	64.99	259.67	36.8	0.0	12.9
February 18, 2019	64.99	380.03	124.03	–87.3	0.0	0.0	258.14	100.03	450.03	5.0	53.9	73.3
February 19, 2019	462.03	392.03	124.03	610.9	3.2	0.0	361.55	100.03	450.03	40.1	0.0	0.0
February 20, 2019	462.03	397.03	124.03	0.0	1.3	0.0	380.26	100.03	500.03	5.2	0.0	11.1
February 21, 2019	64.99	290.03	124.03	–85.9	–27.0	0.0	280.03	502.03	270.03	–26.4	401.9	–46.0

Source: Own calculations

Figure 6: Payment matrix, 14 February 2019, period 20

J1 \ J2	C2C2	C2P2	P2P2	P2C2	Player Payment
C1C1	206,101,000	206,101,000	206,101,000	206,101,000	J1
	10,746,695	8,585,676	-	2,161,019	J2
C1P1	164,656,800	164,656,800	164,656,800	164,656,800	J1
	10,746,695	8,585,676	-	2,161,019	J2
P1P1	165,776,800	165,776,800	165,776,800	165,776,800	J1
	10,805,095	8,644,076	-	**2,161,019**	J2
P1C1	**207,221,000**	**207,221,000**	**207,221,000**	**207,221,000**	J1
	10,805,095	8,644,076	-	**2,161,019**	J2

Figure 7: Payment matrix, 15 February 2019, period 20

J1 \ J2	C2C2	C2P2	P2P2	P2C2	Player Payment
C1C1	99,481,087	99,481,087	99,481,087	99,481,087	J1
	18,557,695	14,834,476	-	3,723,219	J2
C1P1	79,522,257	79,522,257	79,522,257	79,522,257	J1
	18,557,695	14,834,476	-	3,723,219	J2
P1P1	79,835,318	79,835,318	79,835,318	79,835,318	J1
	18,616,095	14,892,876	14,892,876	**18,616,095**	J2
P1C1	**99,794,148**	**99,794,148**	**99,794,148**	**99,794,148**	J1
	18,616,095	14,892,876	14,892,876	**18,616,095**	J2

Figure 8: Payment matrix, 19 February 2019, period 20

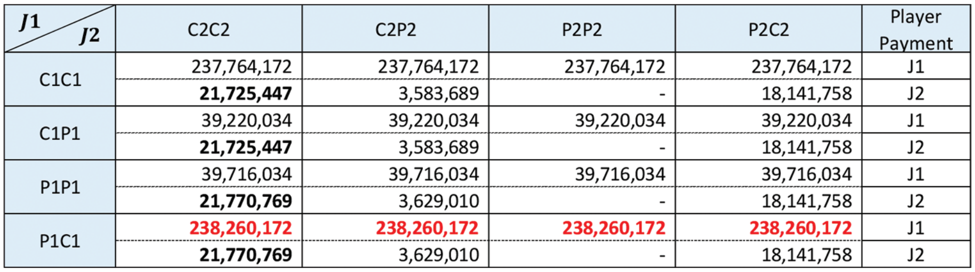
J1 \ J2	C2C2	C2P2	P2P2	P2C2	Player Payment
C1C1	82,752,248	82,752,248	82,752,248	82,752,248	J1
	14,055,480	11,232,864	-	2,822,616	J2
C1P1	66,133,974	66,133,974	66,133,974	66,133,974	J1
	14,055,480	11,232,864	-	2,822,616	J2
P1P1	66,473,096	66,473,096	66,473,096	66,473,096	J1
	14,113,080	11,290,464	-	2,822,616	J2
P1C1	**83,091,370**	**83,091,370**	**83,091,370**	**83,091,370**	J1
	14,113,080	11,290,464	-	2,822,616	J2

cost less than or equal to the bid price; for this case it is assumed that the cost is 2 $/kWh cheaper than the bid price. A value of $\rho=0.8$ is also indicated, close to 1 because the date analyzed corresponds to a scenario in which the pivotal condition is certain according to the RSI.

In the payment matrices for each player (Figures 6-8) the strategies yielding the greatest benefit to each player are identified. On February 14th, it is observed that the action giving player 2 the greatest benefit corresponds to bidding its marginal cost $\{C2;C2\}$ regardless of the nature type of player 1. On the other hand, it is identified that the strategy yielding the best payment to player 1 corresponds to $\{P1;C1\}$ corroborating that the generation plants' bidding strategy follows the PBE found theoretically. Likewise, the plants' strategy for days 15 and 19 also follows the PBE determined theoretically.

For the other scenarios (days) selected from other months, the same procedure was followed and similar results are observed; identical or similar bid prices for different agents and high increases in bids, which allow to confirm the consistency of the model under pivotal conditions.

Figure 9: Payment matrix for January 20 2019, period 20



J1 \ J2	C2C2	C2P2	P2P2	P2C2	Player Payment
C1C1	237,764,172	237,764,172	237,764,172	237,764,172	J1
	21,725,447	3,583,689	-	18,141,758	J2
C1P1	39,220,034	39,220,034	39,220,034	39,220,034	J1
	21,725,447	3,583,689	-	18,141,758	J2
P1P1	39,716,034	39,716,034	39,716,034	39,716,034	J1
	21,770,769	3,629,010	-	18,141,758	J2
P1C1	**238,260,172**	**238,260,172**	**238,260,172**	**238,260,172**	J1
	21,770,769	3,629,010	-	18,141,758	J2

Table 5: Input variables for the pivotal scenario signaling game of February, 2019

Info. type	Variable	February 14	February15	February 19
Real	Period	20	20	20
	J1	Porce 3	Porce 2	Porce 3
	J2	Urra	Urra	Urra
	SP	296.03	510.03	392.03
	G1	700000	195663	211952
	G2	73000	73000	72000
	P1	296.03	510.03	392.03
	P2	450.03	450.03	450.03
Random	ρ	0.8	0.8	0.8
	μ	0.5	0.5	0.5
	μ'	0.5	0.5	0.5
Assumed	C1	294.03	508.03	390.03
	C2	448.03	448.03	448.03

Source: Own calculations

Table 6: HBP for January 21, 2019

	January 20, 2019	
Period	**National HBP**	**Marginal Plant**
17	160.145	San Carlos
18	160.145	San Carlos
19	195.145	Calima
20	200.145	La tasajera
21	200.145	La tasajera

Source: Own calculations

Table 7: Input variables for the non-pivotal scenario signaling game of January 2019

Info. type	Variable	January 20
Real	Period	20
	J1	San Carlos
	J2	La tasajera
	PB	200.145
	G1	1,240,000
	G2	226607.4
	P1	160.145
	P2	200.145
Random	ρ	0.2
	μ	0.5
	μ'	0.5
Assumed	C1	158.15
	C2	198.15

Source: Own calculations

3.4.2. Scenario without pivotal condition: January 20, 2019

For this day no market agent presents an RSI lower than 1.19; EPM had the lowest value with 1.46. Table 6 contains the list of marginal plants that determined the HBP during the periods of highest demand of the day. In order to testing the signaling game, at least one of the marginal plants and another one are used randomly, and thus, the possible behaviors are observed.

Table 7 exhibits the players and the information used to contrast the signaling game. The same assumption used in the pivotal scenarios is made with respect to the costs of the generation plants. On the other hand, a value of ρ=0.2 is defined, close to zero because the probability of pivotality is very low. The results obtained are exhibited in Figure 9, where it is observed that the plants' bidding strategy allows them to obtain the highest payment following the PBE determined theoretically.

For the rest of scenarios (days) in absence of pivotality, the results obtained were similar to the above case, so such information is not included in the paper.

4. CONCLUSIONS AND POLICY IMPLICATION

Throughout this work, a signaling game (sequential Bayesian game) was designed to represent the behavior of generation companies in the energy market, characterized by its oligopolistic nature. The game stands out because of its representation simplicity and because it reflects the behavior of a market in which daily energy auctions are held and where bid prices are subsequently revealed, allowing opponents to know the market strategy in the future. The added value of the model's simplicity lies in that its graphical representation allows for an easy understanding of the structural basis of an energy market and the fact that it can be modified or altered to reflect the realities of other markets or, in the case of a regulator, to observe behavior when incentives or disincentives are added. Although the proposed signaling game was conducted taking as a basis the reality of the Colombian electricity market, eventually the model could be applied to any other market with similar characteristics to the WEM in Colombia.

Theoretically, and through the application of game theory, it was confirmed that, on the energy exchange market, generation companies have incentives to increase their bid price and obtain greater benefits; similarly, it also emerged from the obtained PBE that generation companies collude implicitly as they look for their prices to be similar although they tend to be higher than their marginal costs. The game was also contrasted with actual data for the Colombian market, showing that the bidding strategy follows what was proposed in the signaling game.

On the other hand, market power in the Colombian market and the two companies in the sector that consistently hold a pivotal condition were both confirmed through the RSI. It was argued that the occurrence likelihood of market power abuse is high since actual data from the companies' bids show considerable variations when pivotal conditions exist. The latter raises concern as the demand is currently incurring high energy payments; the intervention of the regulator is required so that it establishes mechanisms that promote competition or keep the possible market power abuse under control.

Finally, recommendations for a possible future analysis are as follows. First, payments established in the signaling game could be modified to reflect a more complete market where revenues from both sales on the market as well as trade in the balancing market are disclosed. This would allow to further understand the strategies of plants with high variable costs (thermal), but it would also imply the addition of more variables and conditions to payments for which computational algorithms for finding the PBE may be required. Second, the bilateral contracts market (long term) could also be included as another set of actions. And third, although the RSI used to determine agents' pivotality includes the amounts of energy contracted in the forward market, verifying the maximum contracting level that an agent could have for its market power to be lost would be recommended, as it is a tool the regulator could use to mitigate market power by rendering energy-contracting mandatory.

5. ACKNOWLEDGMENT

We thanks Alianza EFI-Colombia Científica grant, codes 60185 and FP44842-220-2018 for financial support.

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