# A model of strategic behavior for decision-making and risk management in a wholesale electricity market

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# 1 Introduction

Price estimations become a key issue when defining strategies and managing electricity risks. Price behavior models can not ignore the specific characteristics of the electricity systems. Physical elements, such as operational constraints, seasonality in both supply and demand, or transmissions constraints, among others, are fundamental drivers of electricity prices. The market structure and the strategic behavior have to be explicitly modeled, allowing the price to be an endogenous variable in the decision-making and risk management processes [1].

Therefore, the choice made when defining price behavior models turns to be critical, especially in those immature markets (as is frequently the case with electricity markets), where the mathematical treatment of historical data is of little use. In these kind of markets, a well-defined price model that considers the behavior of agents when facing different market structures and competitors behavior, becomes the best way to define price series.

This paper presents a model of strategic interaction for a wholesale electricity market. In this model the different market participants generate their bids taking into account their cost structures, the operational constraints of their generation plant, as well as other regulatory factors that influence market behavior. The model computes based on the agent's bids, wholesale prices, the resulting dispatch of the units, and the revenues and costs of each market participant.

In the model, market agents are assumed to maximize their profits without a priori knowledge of their competitors' actions. Each participant manages a portfolio of generation stations, both thermal and hydro, and makes decisions on their unit's physical operation and bids.

The overall results are likely to differ with the production and the demand's structure. Under an oligopsonistic and oligopolistic markets, strategies and results will shift from those obtained in the competitive case. Most models applied to the electricity sector focus on different production structures, considering both competitive and oligopolistic strategies, while keeping the demand side behaving as competitive agents. Models applied to other commodities [2] have shown the important influence that concentrated demand's structure has on the strategies chosen by all agents and therefore, on the market's results.

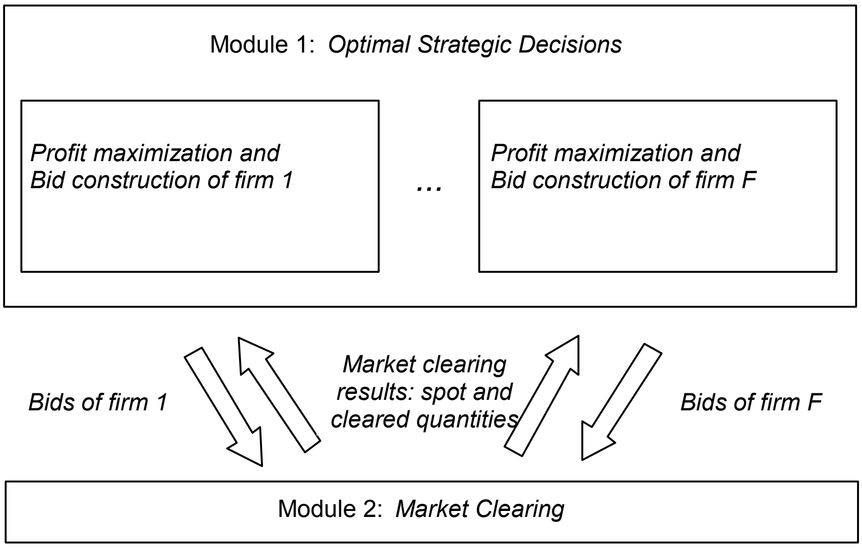
The model can be used to test the effect of different bidding strategies and market structures (ranging from price wars to oligopolistic and oligopsonistic equilibria) in real size markets, and adequately reflects the effects of costs, technical constraints, regulatory elements, etc [3].

The market model follows the ideas proposed by Robert Wilson [4] for the Californian market that led to market equilibrium. The strategic behavior of the generating companies is modeled based on a generalization of the Cornet and Bertrand equilibria, as agents choose their two strategic variables: prices and quantities.

## 2 Market simulation model

The model aims to simulate the agents' behavior in a pool-based electricity market. It is assumed that electricity producers and consumers send their bids to a central agency, which clears the market by using a specified algorithm. The bids are computed independently by each agent, taking into account the others agents' actual or assumed behavior. Consequently, in order to compute the market equilibrium, the proposed model iterates two different modules linked by the information they exchange between each other. In the *Optimal strategic decisions module* (Module 1), firms receive market prices and dispatches from the *Clearing module* (Module 2), and decide new offers (both in quantity and price) that are sent back to the *Clearing module*.

This iterative method reaches convergence when market prices have not changed from one iteration to another in more than a certain threshold; i.e. firms have not changed their offers as they have reached their best and feasible strategy.




· *Clearing module:* The clearing method computes the spot price as the result of a double auction. Technical constraints and fixed costs are not explicitly taken into account in the clearing process, and thus generators have to internalize them in their offers. This is carried out in the strategic module. In any case, most complex clearing algorithms could be implemented.

· *Optimal strategic decisions*: In this module agents decide their offers considering the results of the last iteration as a way of taking into account the competitors' behavior. To assure convergence, these modifications can only be reductions of the selling prices, being the price decrement ($\varepsilon_s$), the aforementioned threshold, fixed. Similarly, modified buying prices must increase at least $\varepsilon_b$.

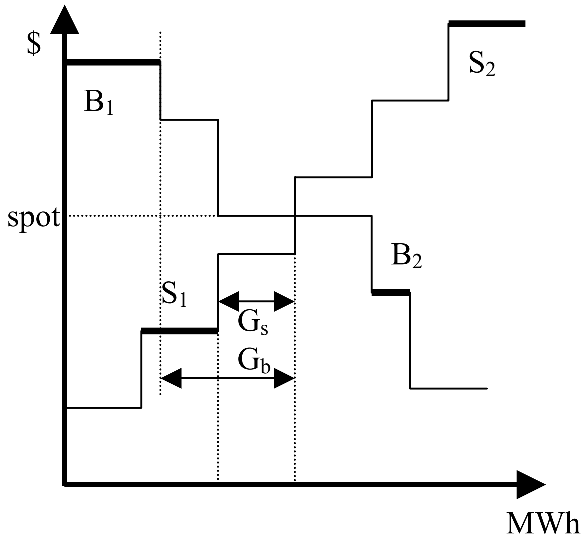
Note that the algorithm converges when each agent can not improve its profit, given the others agents' bids. In that sense, the computed solution is a game equilibrium, and therefore it can be argued that it is a market equilibrium.

## 2.1 Clearing algorithm

For each period, agents send bids consisting of pairs (price ($), quantity (MWh)) The selling bids are stacked in increasing prices order, and the buying bids in decreasing prices order. In addition, an exogenous inelastic demand (a buying bid with a very high price) is considered. The intersection point between the buying and selling offers defines the spot price. The selling bids with prices below the spot price are accepted, and the ones with prices above the spot price rejected. Conversely, buying bids with prices above the spot are accepted and the ones with prices below the spot rejected. Special rules are invoked for those bids at the spot price.

## 2.2 Optimal strategic decisions

Each agent receives the clearing algorithm results. In a given period they could be as shown:




In the figure, an agent has presented the selling bids $S_1$ and $S_2$, and the buying bids $B_1$ and $B_2$. This agent considers the possibility of modifying its bids in the considered period. However, this agent will try not to increase its net sold power in more than $G_s$, in order to do not displace bid $S_1$. Likewise, it will not try to decrease its net sold power in more than $G_b$, in order not to displace $B_1$. The agent will assume that if the net sold power is increased the spot will fall in $\varepsilon_s$, and that if the net sold power is decreased the spot will rise $\varepsilon_b$. Thus, the production of each unit is decided by solving the following optimization problem:

maximize Total profit for periods k=1,...,N

s.t. -Technical constraints
-Increased net sold power in period k bounded below by $-G_s$ and above by $G_b$
-If the net sold power does not change, the spot will be not change either.
-If the net sold power increases, the spot decreases in $\varepsilon_s$.
-If the net sold power decreases, the spot increases in $\varepsilon_b$

Some remarks may be in order:

1. This optimization problem can be formulated as a mixed linear integer program. Therefore, it can be solved by standard and highly efficient commercial codes.

2. Technical constraints include maximum and minimum generation powers, ramp constraints, and hydro balance equations for hydro and pumping units.

3. Note that the spot for each period, $\varepsilon_s$ and $\varepsilon_b$ are fixed parameters for the optimization problem. Therefore, very complex profit functions including not only operation costs (including variable, fixed and start-up costs) and market income, but also stranded costs payments and a wide variety of contracts can be considered.

4. The assumption on the spot change with the net sold power (the last restriction) can be substituted for more involved conditions implying the whole residual demand curve seen by each utility. It is not clear, at the moment, if the results are improved enough to justify the added complexity.

5. With this formulation companies can manage buying and selling units, with different concentration levels on both sides. Therefore selling companies and buying companies are only particular cases where agents only manage a certain unit type.

Once that the optimization problem is solved, the price of the bids that in the previous iteration were not accepted by the clearing algorithm, but which are expected to be accept in order to comply with the optimization results, are updated.

## 2.3 Initial bids

A set of initial bids is needed, in order to begin with the iterative procedure. Initial selling bids are set to a high value, in order to recover the total cost of the generating units even if the unit is only scheduled on a single period. Likewise, initial buying bids are set to low values.

# 3 Case example

The example presented corresponds to a realistic wholesale market over a year. The simulated year is divided into thirteen periods with two subperiods each, week days and non-week days, and three different load levels for the week days and two for the non-week days. Four generating companies are modeled with different market shares and technologies (FA, FB, FC and FD). These companies manage in total 67 thermal units, 19 hydro units and 9 pumping units. A buying company for the oligopsonic simulations is also considered. No technical constraints are considered for the consumption units, only a power profile and a reservation price for each load level is modeled. In the simulations where the oligopsonistic behavior is considered, these units are managed by the consumption company. A certain fraction of inelastic demand is always taken into account.

Four simulations are presented in this paper:

- Case #1: It follows an oligopolistic strategy where the generating companies maximise their profits while the demand is completely inelastic (126,255 GWh). No pumping is allowed in this simulation.
- Case #2: It follows an oligopolistic strategy where the generating companies maximise their profits while the demand is completely inelastic (126,255 GWh). The generating companies manage pumping resources. The pumping consumption can behave as a strategic consumer in this simulation.
- Case #3: It follows an oligopolistic strategy. A certain fraction of the demand remains inelastic (69,440 GWh that corresponds to the 55% of the simulation carried out in Case #1). The 45% of the demand is offered by the ten consumption units which are managed by the oligopsonistic company (56,815 GWh).

- Case #4: It follows an oligopolistic strategy. The percentage of the demand that is inelastic and the percentage that behaves as a strategic agent has now been changed to 85% inelastic (18,938 GWh) and 15 % strategic (107,317 GWh).

From the analysis of these four simulation two different effects can be seen, the strategic behaviour of the pumping units and the strategic behaviour of the demand.

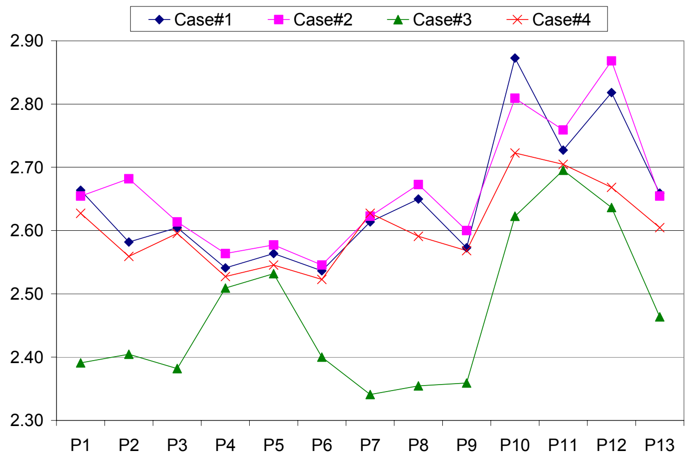



**Figure 1: Market Prices for each period (¢/kWh)**

- Strategic behaviour of the pumping units:

The prices for each period obtained for the two fist cases are reported in Figure 1 and for each load level in Figure 2. Prices are slightly higher when pumping are allowed to operate than without these units, especially during the valley hours where pumping energy is bought. Although some pumping units might generate at a loss, all the generating companies increase their profits when pumping is considered. The profits increase specially affects those companies that manage the pumping units and have high inframarginal energy during valley hours. Therefore valley prices are raised which increases valley profits and in turn increases the overall profits even though some of the pumping units generate at a loss.

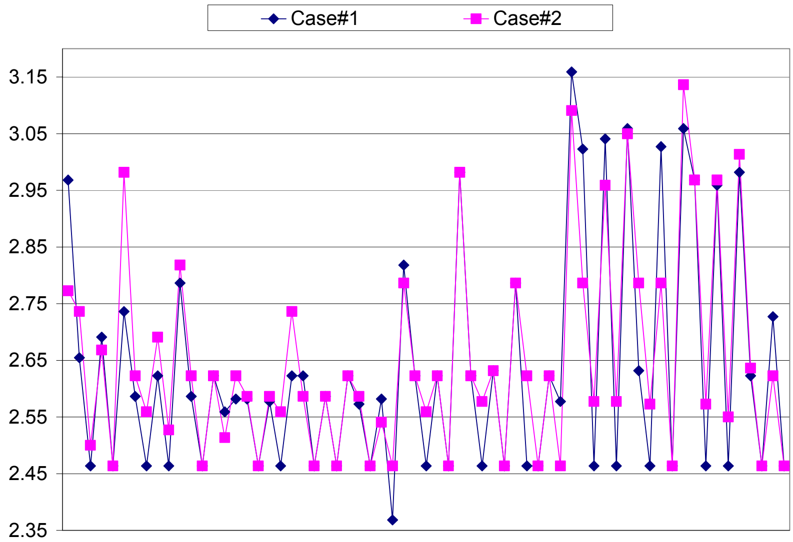



**Figure 2: Market prices for each load level in Case#1 and Case#2 (¢/kWh)**

- Strategic behaviour of the demand:

As it can be seen in Figure 1 the effect of the consumer's oligopsony counteracts the strategic behavior of the oligopolistic producers. Prices obtained from Case #3 are lower than those in Case #1 where the demand was totally inelastic. The final served demand is reduced in this case (114,803 GWh) as the consumption agent withholds its demand in order to decrease prices, as it can be seen in Figure 3. The profit of this agent increases due to the price reduction (a 30 % compared to Case#1), while the production profit decreases as not only the production is reduced but the prices at which these companies sell their energy are also lower (these profits decrease in percentages that range from a 12% to a 29%). Case #4 corresponds to an oligopsonistic behaviour where the percentage of the strategic demand is lower than in Case #3. Thus, prices do not fall as much as in the previous example, and the consumption's reduction is also lower (11,318.8 GWh).

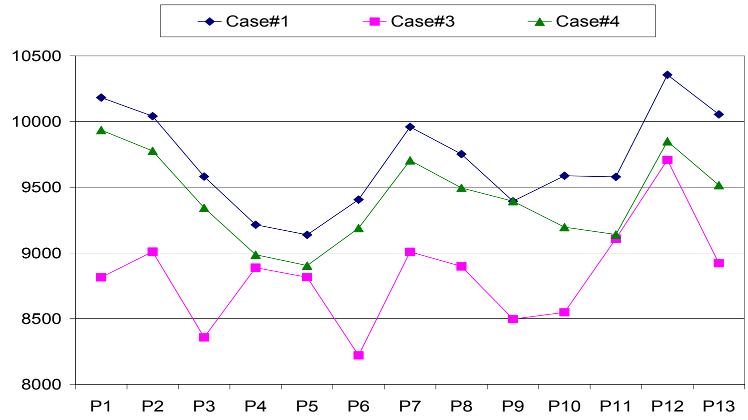



**Figure 3: Demand traded in Case#1, Case#3 and Case#4 (GWh)**

# 4 Conclusions

In this paper we have presented a market model that focuses mainly on the effect of different strategies and different competitors behaviours. It models the strategic behaviour of generation companies when they face a certain market structure and regulation, and handles both the economic objectives of these companies and their operational and technical requirements. The strategic behaviour of the consumption companies has also been represented and has proven to have a strong influence on the market results.

# 5 References

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