A Contribution in Experimental Economics to Classify Market Power Behaviors in an Oligopolistic Power Market

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Abstract-- **The approach of experimental economics is used in this paper to show that other behaviors than perfect competition and classical representations of imperfect competition can be relevant to study a power market on a constrained network. Human subjects compete on a market to maximize their profit while they are located in two different geographical areas with limited interconnector capacity. The eight experiments we run lead to a better understanding of how market power is exercised by the duopoly or the triopoly, how it can influence an adjacent competitive market and a characterisation of subjects' behaviour. We find out that subjects' behaviours can be classified into three main classes: leaders, who take risk to raise prices, followers who bid according to their expectation of leaders' decision, and price takers who bid their marginal price whatever the market conditions. The presence of one leader and several followers is usually sufficient to observe significant use of market power.**

I. INTRODUCTION

THE ongoing liberalization process of electricity markets has initiated an important evolution of the industry structures over the world. A major goal of the reforms was to achieve economic efficiency and lower electricity prices by introducing competition in former regional electricity markets. In this context, the interconnectors, which link the regional transmission systems, play a major role for competition because they stand for immediate competitors to the old national power monopolies [1].

Therefore, the electricity market integration requires well designed rules in order to allocate efficiently scarce transmission capacities among market participants. From the point of view of maximizing social welfare, the most efficient method applied in Europe to cope with the limited interconnector capacities between regional systems is called "implicit auction" [2], [14]. This method requires "perfect competition" to achieve full efficiency. That is to say that the generators bid their marginal price (and consumers their marginal utility), and do not try to modify price to increase their profits.

But market participants may have non-competitive behaviors and use market power to alter profitably prices away from competitive levels [12]. A large consensus among economists states that oligopoly induces an important market power for its participants. The recent merging of generation utilities has reinforced the oligopolistic context remaining from the former regional monopolies. Most of European regional electricity markets have thus reached a high level of market concentration. For instance, there is monopoly in France, Belgium and Greece, duopoly in Spain, Finland, and Sweden, triopoly in Germany or quadripoly in United Kingdom [3], [4], [5], [6], [15]. The high market concentration is thus a serious threat for the economic efficiency of the electricity markets.

Numerous economic studies have already modeled the use of market power in presence of transmission constraints. These studies of imperfect competition with transmission constraints traditionally rely on Game Theory [7], [8], [9], [16]. Most of these approaches also assume that all market participants have perfect information and perfect rationality. They can then compute and play the Nash equilibrium.

However, real market participants only have imperfect information and process it with a bounded rationality to make decisions. The bounded rationality may also vary between the

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market participants. Given different cognitive abilities of market participants, they may be more or less opportunistic. Market participants may then have different behaviors regarding market power, some trying to increase the market price to make more profit, others being more passive and bidding at marginal price. Although, these different behaviors have been noticed on electricity market [10], they have seldom been modeled or explained. There may then exist a wide variety of behaviors between perfect competition and classical representations of imperfect competition described by game theory. This paper analyzes human behaviors in an electricity market with congestion and proposes a classification of these behaviors.

A (fairly new) research method that takes into account these imperfections in economics is the experimental approach. Experimental economics shows indeed some properties that are decisive for a better understanding of the use of market power in electricity market. The approach of experimental economics allows taking into account human decision making in complex situations [11]. As long as a set of conditions is respected (e.g. if the experiment is simple enough for players to understand their impact and for economists to analyze results properly), experimental economics can provide useful information in seven cases listed by V. Smith. Two reasons out of these seven cases justify the use of this method in this study, namely to compare environments and to establish empirical regularities as a basis for a new theory.

The experimental approach is usually used to characterize market designs as for the opportunity to use market power [11]. This paper considers a different use of experimental economics through a classification of market participants' behaviors. Three types of market behaviors are indeed highlighted: namely marginal-bidder, follower and leader. This identification is performed studying the use of market power in a simple power network with two regions and a limited interconnector transfer capacity allocated by an implicit auction. The results from experiments are first compared with these obtained with game theory allowing a quantification of the use of market power. Second, we show that these three types of market behaviors can be extracted from the experiments. An accurate characterization of players' behavior may indeed help developing an adequate regulation of new electricity markets.

This paper is organized as follows. Section II describes the experimental design. Section III outlines the experimental process and the theoretical results that should be obtained according to classic game theory. Section IV then presents a complete overview of the results. Conclusions and propositions for further works are eventually presented in section V.

II. EXPERIMENTAL DESIGN AND ASSUMPTIONS

This section sets the characteristics of the power market under study. We start by defining the market structure. Then, we draw up the market design and the interconnector capacity allocation method.

A. Market structure

The market structure is presented in Fig. 1. Generators and loads are located within two zones. An interconnector links these two zones. The transmission capacity of this interconnector is constant for all the experiments.

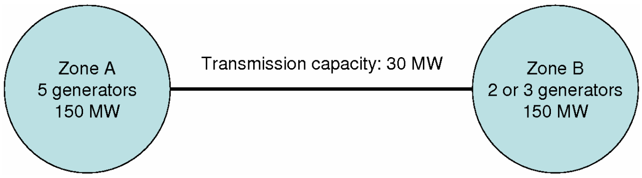

Fig. 1. Market structure

For all the experiments, the demand is represented by predefined demand curves. Two demand curves are used, namely a base load and a peak load demand curve, respectively. They are represented on Fig. 2. The demand curve is constant during each phase of the experiments.

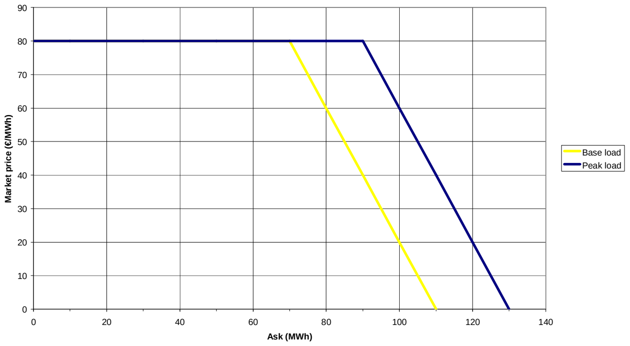

Fig. 2. Demand profiles

The subjects of the experiments only control generators. A global generation capacity of 150 MW is available in each zone. This capacity is equally divided between five generators in the first zone. Depending on the experimental design, the generation capacity in the second zone is equally divided between two or three generators (experimental design 1 or 2, respectively).

The generation costs depend on location. For each generator, half of his generation has a low marginal cost (10 and 15 €/MWh in zone A and B, respectively) and the other half has a high marginal cost (20 and 25 €/MWh in zone A and B, respectively). This framework features a more competitive zone where five generators own a generation capacity of 30 MW at a relatively low cost, and an oligopolistic zone where only two generators can generate up to 50 to 75 MWh at a higher cost. All numerical details are summed in Table I.

Demand profiles are chosen in order to control the generators' ability to use market power unilaterally or not. Additionally, under competitive assumption, the line should be congested at peak load, but not at base load. The ability to exercise market power is affected in the experimental design 2 by splitting of the two generators in zone 2 into three.

TABLE I NUMERICAL DATA BESIDE GENERATORS

Zone	Experimental design	Unit type	Marginal gen. cost (€/MWh)	Available quantity (MW)
A	1 and 2	Low cost	10	15
		High cost	20	15
B	1	Low cost	15	38
		High cost	25	37
	2	Low cost	15	25
		High cost	25	25

B. *Market design*

The interconnector capacity is allocated according to the method known as "implicit auction" or also as "market coupling mechanism" [14]. In this context, each zone has a local power market, where only generators that are physically located in the same zone can bid through a uniform price sealed auction. These local markets are coordinated so that the interconnector between these markets is efficiently used.

Once offers have been submitted, aggregated bid and ask curves are computed on each market to calculate the two equilibrium prices PA and PB as represented in Fig. 3

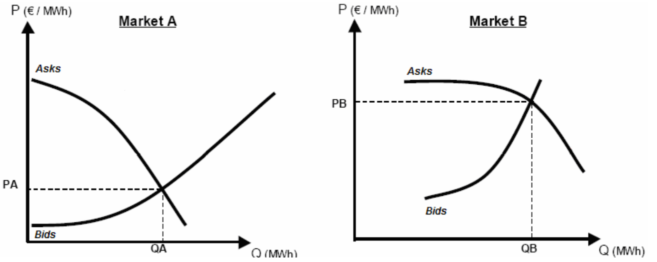

Fig. 3. Ask and bid curves for region A and region B and market results if the markets were not coupled

When the price PB is higher than PA, a quantity ΔQ is exchanged from zone A toward zone B. This export is equivalent to an additional ask ΔQ at any price in market A while the corresponding import is equivalent to an additional bid ΔQ at any price in market B. This quantity ΔQ is progressively raised from zero until one of the following cases is reached:

- Fig. 4 illustrates the first case. There is no congestion.

The quantity exchanged ΔQ = QA* - QA = QB* - QB (export or import depending on the considered zone) is then smaller than the available transfer capacity of the interconnection A-B. As we can see in figure 4, there is thus only one price P* = PA* = PB* for both markets.

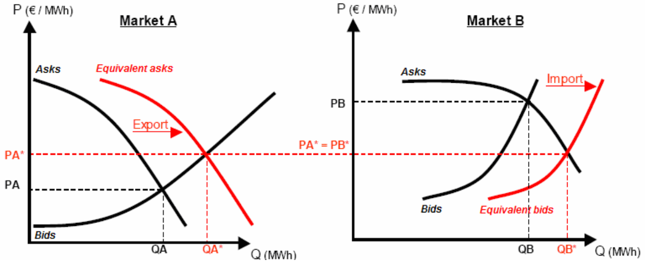

Fig. 4. Market clearing when the interconnector A-B is not congested

- Fig. 5 exemplifies the second case. There is a congestion between the zone A and B.

The quantity exchanged ΔQ = QA* - QA = QB* - QB is equal to the Available Transfer Capacity of the A-B interconnection. Fig. 5 shows that there is one price for each market.

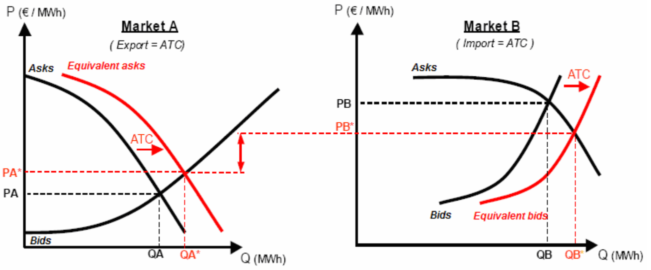

Fig. 5. Market clearing when the interconnector A-B is congested

In both cases, once equilibrium prices have been computed, the bids submitted in the market X (A or B) are:

- fully accepted when the offered price is below PX*;
- fully rejected when the offered price is above PX*;
- partially accepted when the offered price equals PX*.

III. EXPERIMENTAL RESULTS

Before analyzing the experimental results, we present the experimental process. Then, we recall the results obtained with the game theory approach and we compare the results of the different experiments with these theoretical results. Finally, we present a categorization of behaviors that we can draw from the experiments.

A. *Experimental process*

Eight experiments were run with different settings and subjects from various origins, as shown in Table II.

TABLE II: DISTRIBUTION OF THE SUBJECTS BY EXPERIMENTAL DESIGN AND BY ORIGINS

Experimental design	Designation	Subjects origin	Number of experiments	Number of period per experiment
1	11, 12, 13	Students in engineering	3	60
	14	PhD students & faculty members (non-economists)	1	60
	15, 16	Students in engineering	2	40
2	21	Students in engineering	1	60
	22	Similar to 14	1	60

1) *Instructions*

Every experiment is foregone by thirty minutes of instructions. The market structure is described and the market design is detailed. The subjects are also taught how to use the experimental interface. Two demonstration periods close the instruction phase so that every subject is familiar with the interface.

The subjects are given the phase parameters (demand curves and available transfer capacity) and they are warned at the beginning of each phase. They know the total amount of generation capacity available per zone (150 MW) but they are not told about other subjects' costs and capacities.

2) Experimental progress

Each session lasts from one hour to one hour and a half depending on the number of periods. During the first periods, the subjects have sixty seconds to submit their bids; this term is progressively decreased when subjects get trained. However time is never binding during the experience.

Subjects can submit and modify as many bids as they want. Nonetheless the offered quantities and prices must be integers not only for computational purposes, but also to accelerate price convergence. In addition to information on the market price evolution in each zone, subjects have access to their last three periods' profits, their aggregated profits, results for each previous period bids (fully accepted, partially accepted or rejected). There is no transaction cost and generation costs are only due for sold units.

B. Theoretical results

To analyze the results of the experiments, we first compare them with the results of game theory. The competitive and (static) Cournot equilibriums are computed for each experimental design and each phase according to the definition given in [9]. Tables III and IV present the theoretical results corresponding to the experimental designs 1 and 2.

Since the unique difference between them is the market structure ("concentration") in zone B, the results corresponding to the perfect competition case are equivalent. In these cases, the difference between phase 1 and 2 is the occurrence of congestion. In phase 1, both regional markets achieve the same price since there is no congestion. In phase 2, the price in zone B is higher than the price in zone A because the interconnector is congested.

When considering Cournot competition, market structure is important and this can be seen comparing the results from experimental design 1 and 2. It is important to note that the computation of the Cournot equilibrium is based on the assumption that players do not try to "game" transmission pricing [16]. The Cournot prices of experimental design 1, which corresponds to a more concentrated market structure in zone B, are higher than prices of experimental design 2.

TABLE III: PRICE EQUILIBRIUM FOR EXPERIMENTAL DESIGN 1

Phase	1 (no congestion)		2 (congestion)	
Price zone	A	B	A	B
Perfect competition	20,0	20,0	20,0	25,0
Cournot	43,6	44,0	47,3	52,0
Unilateral market power	NP	25,0	25,0	NP

TABLE IV: PRICE EQUILIBRIUM FOR EXPERIMENTAL DESIGN 2

Phase	1 (no congestion)		2 (congestion)	
Price zone	A	B	A	B
Perfect Competition	20,0	20,0	20,0	25,0
Cournot	40,8	40,8	47,3	50,0
Unilateral market power	NP	25,0	25,0	NP

Moreover, the price obtained when only one player uses market power is determined. "NP" means that no player can unilaterally and profitably raise the market price above the competitive one. One can notice that in phase 2, any generator in zone A is pivotal. Under these circumstances, unilateral exercise of market power in zone A leads to a leveling of prices in both zones.

C. Comparison of experimental results with Game Theory

Tables V and VI below present the market price reached in each zone at the end of each phase. When no convergence was reached, the price is the average of the last twenty periods and is indicated by a star "*".

TABLE V: RESULTS FOR EXPERIMENTAL DESIGN 1

Phase	1 (no congestion)		2 (congestion)	
Price zone	A	B	A	B
Perfect competition	20,0	20,0	20,0	25,0
Cournot	43,6	44,0	47,3	52,0
Unilateral market power	20,0	25,0	25,0	25,0
11	21	24,2*	24,7*	26,1*
12	25,3*	25,6*	28,3*	28,9*
13	21	21	25	25
15	21	70	62*	80
16	21	21	23,8*	28,8*

TABLE VI: RESULTS FOR EXPERIMENTAL DESIGN 2

Phase	1 (no congestion)		2 (congestion)	
Price zone	A	B	A	B
Perfect competition	20,0	20,0	20,0	25,0
Cournot	40,8	40,8	47,3	50,0
Unilateral market power	20,0	25,0	25,0	25,0
21	21	21	31,9*	36,2*
22	20,8*	20,9*	24,3*	25,6*

Since the offer price must be an integer, a market price of 21 instead of 20 €/MWh is considered close to the competitive price. Indeed, the subjects' profits are similar if their bids are accepted at a price of 20 €/MWh or if they are rejected. The subjects' profits would be zero in both cases. As a consequence he may bid just above his marginal cost.

In the first phase, the market is often close to the perfect competition model. In the second phase, results are quite similar to the unilateral use of market power. In accordance with the results predicted in subsection III.B, market prices in both zones remain rather close, particularly in phase 2.

However, the market prices are far from (static) Cournot's model expectations, and it is necessary to study individual behaviors in order to understand this divergence.

D. Characterization of the subjects' behavior

In order to characterize the subjects' behavior, we propose a classification based on their offer functions. Experimental economics offers the possibility to observe the exercise of market power by comparing bids with generation costs. Since the price can never be below 20 €/MWh by assumption, the bids associated with the cheapest generation (10 or 15€/MWh) are not significant[1].

To measure the market power of the subjects, we use a markup index. The markup is the difference between the bid price and the marginal generation cost. Since the offered price must be an integer, a markup equal to 1 is considered as a competitive behavior. Even under this condition, Fig. 6 shows that hardly half of the significant units are offered at a competitive price in zone A, and less than a third in zone B. Besides, all withdrawn units are represented with a markup of 100 €/MWh. Fig. 6 then shows that the strategy to withdrawn capacity is current one in zone B where withdrawn capacity stand for 40% of total generation capacity.

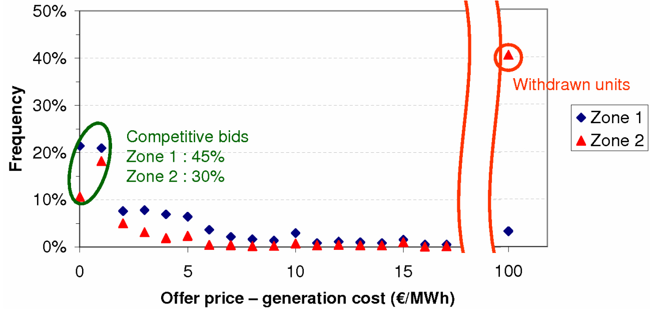

Fig. 6. Price markup by zone

The experiments show that the subjects do not only refer to their marginal cost, but also to the market price of the previous period. Fig. 7 represents the distribution function of the difference between the offer price and the previous market price (without taking into account the competitive bids).

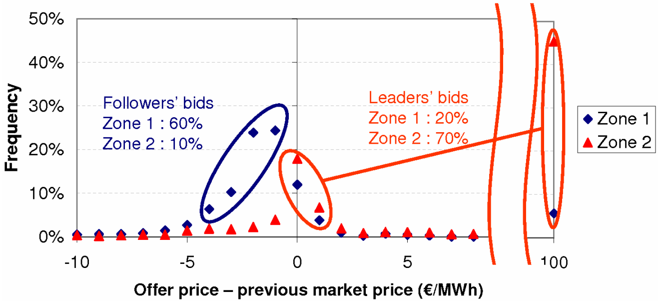

Fig. 7. Difference between offer price and previous market price

This figure displays two different behaviors for bids which are not offered at their marginal cost. First, the price can be chosen above the previous market price, or even withdrawn as this is the case for almost half of the non-competitive bids in zone B. These behaviors, and particularly capacity withdrawal, is an attempt to raise the market price and is a feature of a price-maker or leader strategy.

Second, half of the non-competitive bids on zone 1 is offered at the previous market price minus 1 or 2 €/MWh. This strategy can be qualified as "follower behavior". By bidding just below the previous price, the subject aims at preventing a price drop whilst limiting the risk for his offer to be rejected.

This strategy is a clear incentive for a leader to raise the price punctually even if it is not immediately profitable. Indeed, the price decrease is slow enough for it to earn more during the next periods than its losses the period when it used its market power. The subjects can then reach an implicit collusion similar to the one observed in a repeated Stackelberg game, in which the follower plays depending on the leader's previous period decision. An even stronger implicit collusion was observed during the experiment 16 in which the two generators of the second zone implicitly agreed to bid at the monopoly price.

As a result, we can classify the behavior of market participants in three different types: 1° the competitive or price-taking behavior, 2° the leader or price-making behavior and 3° the follower behavior.

E. Impact of players' behavior on the market price and its evolution

An experiment involving some few leaders and several followers results in prices significantly higher than the competitive price. Fig. 8 shows such a situation where the leader behavior increases price while the follower behavior makes it decrease slowly. Once the competitive level is reached again, one of the leaders uses market power to increase, etc. Price then does not converge, but a dynamic equilibrium is found. The price variation is a sequence of peaks followed by slow decreases (over five to ten periods).

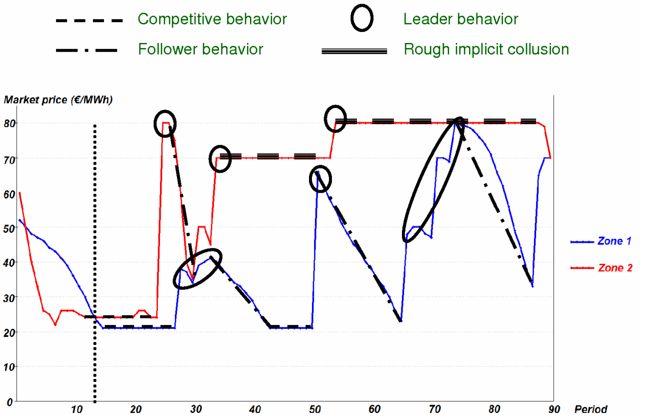

Fig. 8. Illustration of the different behaviors during an experiment. Small dashed lines represent competitive behavior. The lines and points stand for the follower behavior. The leader behavior is circled. And the big dashed lines signal implicit collusion.

In particular, when the interconnector is such that all the excess generation in zone A can be exported into zone B, congestion leads to a raise of the market price in zone A up to

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[1] The corresponding price can range from their generation cost (10 or 15 €/MWh) to the competitive price (20 or 25 €/MWh) without neither any particular reason nor any consequence on the market price.

its level in zone B. Simultaneously, as soon as the interconnection is congested, a lack of competition on zone B results in a price increase, from which a vicious circle may ensue.

IV. CONCLUSION

Although the experimental design under consideration is extremely simple, it contributes to a better understanding of the use of market power. This analysis is supported by a classification of the subjects' bids. Three main types of bids could indeed be clearly identified. This possible quantification of each type of bid is an interesting vector toward understanding the evolution of the market price. Future works are expected to depict more accurately the evolution of market price depending on the quantity of bids in each of the three classes.

The results of this paper can then be used to define market strategies in some agent-based approaches. These approaches model a market as a dynamic system of interacting agents. An agent refers in this context to a bundle of data and behavioural methods representing an entity constituting part of the simulated market [13]. The results presented in this paper can then be combined with more classical theories of imperfect competition. Experimental economics could eventually be useful in order to evaluate the real efficiency of regulation designs.

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VI. BIOGRAPHIES

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