An IPV Auction Model for Strategic Bidding Analysis under Incomplete and Asymmetric Information

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An IPV Auction Model for Strategic Bidding Analysis under Incomplete and Asymmetric Information [♣]

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ABSTRACT

In the competitive electricity markets, information plays a major role; different distributions of information among the market players may impact the market outcomes in terms of prices and surpluses. In this paper we present a model based on the Independent Private Value auction theory to analyze the strategic interaction among producers in the electricity market and its outcomes in different informative contexts. The model is based on a game theory application in which we define a static and simultaneous game with incomplete and asymmetric information. The day-ahead electricity market is considered as a multi-object auction in which each producer owns a multi-plant firm and offers multiple couples of price-power quantities. The model is used to study the market outcomes of different distributions of information levels among the players in markets characterized by the presence of a dominant producer. Numerical examples are provided with reference to the Italian electricity market to illustrate some of the salient market outcomes.

KEYWORDS: electricity market, game theory, auction theory, asymmetric information, bidding strategies

JEL CODE: L97, L5, L21, C3

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1. Introduction

The power industry has been considered for a long time as a natural monopoly. During the last years, competition among producers has been introduced with the aim of reducing the electricity prices to the consumers and increasing the market efficiency. The competition is sought also as a mean to improve technology and facilitate innovation. The establishment of a highly competitive market in the electricity sector is not easily achievable due to the relatively small number of players, which qualifies the electricity market as an oligopoly [1].

In this framework, in a centrally operated pool with a power exchange the procedure adopted for the market clearing is particularly important. Different approaches have been proposed and implemented around the world [2], [3], [4]. The participation of demand side to the clearing may impact significantly the market outcomes [5].

The use of an inadequate procedure for the clearing of the market may lead to high prices, price volatility and unfair appropriation of social surplus by the market players, that is unacceptable from a social and political point of view.

The market clearing process in a power exchange context has been interpreted as a particular form of auction in which the good sold is the electric power to be injected into the grid for a given hour [6], [7], [8], [9]. The total demanded power must be divided among the participating producers, so that the auction determines both winners and their load share. All producers submit a sealed bid composed by a price for each block of generation offered to the market.

We consider a non discriminatory auction for the day-ahead market, in which all generators winning the auction are paid at the uniform Market Clearing Price (MCP), that is the bid price of the most expensive producer needed to completely meet the demand [10].

All producers compete among them to maximise their own surpluses. An auction can be seen as a strategic game with N players [11]. The surplus of each producer is significantly affected by the behaviour of rival producers. Obviously, the optimal bidding strategies and the market equilibrium depend strongly on both the characteristics and the number of producers. In the non discriminatory clearing price auction and in a perfect competitive market, producers should bid at their marginal production costs [12], [13]. With multi-plant firms, because of the unique MCP, if producers have some probability to set the MCP, they would construct portfolio strategies, to obtain a high revenue considering all the contribution of their winning generators.

For the electricity market an auction model based on the IPV (Independent Private Value) assumption is particularly appropriate. In such a model the bidders only know their own costs, though they may have some idea about the costs of the other producers.

In effect, in the electricity market, the actual production cost may be related to a certain set of information that is private information known only by the producer that owns and operates the power plant. Such information include the real management costs, the actual maintenance conditions of plants that may not be optimal, the contractual conditions through which fuels have been bought.

On the other hand, due to the standardisation in the plant technology, some other information constitute a common knowledge for all the producers. Among those the maximum rated power of each plant is known. Also, efficiencies and costs of each competing generator may be estimated with a certain degree of uncertainty. Different knowledge kept by various producers about the production costs of competing generators plays an important role in determining the market outcomes.

Moreover, each producer is influenced in formulating his strategic bids by different variables that can neither observe nor assess sharply as the actual load and the bidding strategies of the other producers [1].

In the next section we introduce a mathematical model which represents the strategic behaviour of each producer in the day-ahead market and emphasises the role played by the information. In section III, we analyse the market equilibrium through some meaningful economic metrics, under different scenarios characterized by a different number of producers with symmetric information [14]. In section IV, we consider different information sets for the producers that leads to an asymmetric information context and we assess their impacts on the market outcomes, with reference to an Italian market where a prevalent producer may operate.

2. Strategic Bidding Model

The model proposed is based on the IPV assumption of the auction theory in which each producer (bidder) knows exactly only the costs associated with his plants and gives an estimation with a certain degree of uncertainty of the costs of the competitors that are related to the offers they will submit.

The market clearing is formulated through a static and simultaneous game in which the information of each player concerning the competitors' costs is expressed in terms of a mean value and a standard deviation (σ) with a normal distribution function. Lower values of σ correspond to a better knowledge of the costs and higher level of information. Different σ allows for modelling the information related with cost of the same producer differently for each competitor, introducing asymmetry in the information.

Each producer defines the bids of his generators with the goal of maximising his expected surplus, defined as the total hourly revenue minus the variable costs. In addition, we define the total producer surplus as the sum of the expected surpluses of all producers.

The demand is a zero-elasticity load whose value is known in terms of mean value and σ with a normal distribution causing the information to be incomplete.

The basic assumptions adopted in the model are:

- we consider a specific hour of the day-ahead energy market, supposing the game as a static game;
- there are N power producers, everyone owner of m^n generation units;
- the marginal costs are constant for each generation unit;
- each *n-th* producer knows only the typology of *j-th* rival generation plants and their generation capacity; therefore, other bidders' costs are random variables drawn from a normal distribution function whose normal density function is defined by $f_u^{nj}(c)$, with a mean η_u^{nj} and a standard deviation σ_u^{nj}. Each producer has his own informative set, so that individual valuations of various producers about production costs of a specific rival generator are independent. This characteristic is typical in an asymmetric information context, in which we assume:

$$\eta^{nj} \neq \eta^{jn} \quad \text{e} \quad \sigma^{nj} \neq \sigma^{jn} \;\; \forall\, n \in N,\, j \in J$$

The symmetric information, in which all producers own the same informative set, may be represented as a particular case:

$$\eta^{nj} = \eta^{jn} \quad \text{e} \quad \sigma^{nj} = \sigma^{jn} = \sigma_C \;\; \forall\, n \in N,\, j \in J$$

- the bidding function increases monotonically. That implies that the probability for a generator to submit a higher bid than a bid submitted by a rival generator is equal to the probability that its production cost is higher than the production cost of rival generators. This assumption is justified by pricing theory in an oligopoly market, based on mark-up concept [1];
- to construct the bids of generators of a generic *n-th* producer, we suppose that the opposite *j-th* producer submits a bid v_u^j equal to the estimated mean of the distribution cost ($v_u^j = \eta_u^{nj}$);
- the load, that is considered fixed, is drawn from a normal distribution function with a mean η_D and a standard deviation σ_D. The information about demand forecast is symmetric, therefore it influences the bids of various producers in the same way. The producers are uncertain not only about other producers bids, but also about the total demand and, consequently, both marginal generator identity and its produced power quantity $p_{u_{\eta_D}}^n$ are random variables.
- we consider neither transmission constraints that can modify the merit order of market dispatching and increase the MCP, nor demand side bidding.

Let's define the set of producers as $N = (1, \ldots\ldots, N)$ with $dim(N) = N$, indexed by *n*. Let's call $U = (1, \ldots\ldots, U)$ the ordered set of generation units with respect to the marginal costs of generators, indexed by *u,* with $dim(U) = U$. Each generator submits a bid indicating a price v_u^n and a power quantity $\bar{p}_u^n$ that it offers at the indicated price.

A generic generator that is owned by producer 1 is indicated with an opportune apex as (p_u^1).

The total power quantity that in equilibrium is supplied to the system depends on realisation of demand η_D. The dispatched generators are identified through the following equilibrium expression:

$$\sum_{u=1}^{u_{\eta_D}-1} \bar{p}_u + p_{u_{\eta_D}} = \eta_D \qquad \text{with:} \quad 0 < p_{u_{\eta_D}} \le \bar{p}_{u_{\eta_D}}$$

where $u_{\eta_D} - 1$ is the number of generators that produce exactly the quantity offered, while u_{η_D} represents the marginal plant that sets the MCP.

At the moment of the bid submissions a bidder doesn't know if his bid will win because the outcome of the auction depends also on the offers of other bidders. It is clear the fundamental *trade-off* that characterises the construction of a bid in an auction: to submit a smaller bid than that submitted by rivals and at the same time to be sure to obtain an expected surplus greater than zero.

The merit order done on the basis of all the bids is the following:

$$U \in \left(\underbrace{1, 2, \ldots\ldots\ldots, u_{\eta_D} - 1,}_{\substack{\text{units that produce}\\ \text{all quantity offered}}} \underbrace{u_{\eta_D}}_{\substack{\text{marginal}\\ \text{unit}\\ \text{that sets}\\ \text{the MCP}}}, \underbrace{u_{\eta_D} + 1, \ldots\ldots\ldots, U}_{\substack{\text{units}\\ \text{not}\\ \text{dispatched}}} \right)$$

The selected generators $M \in \left(1, 2, \ldots\ldots\ldots, u_{\eta_D} - 1\right) \subseteq U$ are paid at the MCP, that is higher than respective bids.

Almost all decisions involve not negligible elements of uncertainty. Economic decisions under uncertain conditions are similar to games of chance.

An important feature of any game of chance is its expected payoff, or rather the pondered mean of winnings and losses, associated to all the possible outcomes, where the weights are represented by the respective probabilities [19].

It is necessary to define the expected surplus and the victory probability for each generator. If we analyse the bidding strategy of *n-th* producer, the other producers belong to the set $J = (1, \ldots\ldots, N-1)$ and they are indexed by j.

In this model, the constructions of valuations of producers are based on hypotheses of the IPV auction theory. The production cost of *u-th* generator of *j-th* rival is considered by *n-th* producer as random variable, with mean η_u^{nj} and standard deviation σ_u^{nj}, drawn from a normal distribution function over $\left[\underline{c}^j, \overline{c}^j\right]$, whose density function is defined as:

$$f_u^{nj}(c) = \frac{1}{\sigma_u^{nj}\sqrt{2\pi}} \exp\left[-\left(c - \eta_u^{nj}\right)^2 \Big/ 2\sigma_u^{nj\,2}\right]$$

The cumulative normal distribution function $F_u^{nj}(c)$ is defined as:

$$f_u^{nj}(c) = \frac{dF_u^{nj}(c)}{dc}$$

The set of generators that are owned by the *n-th* producer is defined as:

$$U^n \in \left(1, 2, \ldots\ldots, i^n, \ldots\ldots\ldots, m^n\right)$$

Similarly, the set of units that are owned by the opposite *j-th* producer is defined as:

$$U^j \in \left(1, 2, \ldots\ldots, i^j, \ldots\ldots\ldots, m^j\right)$$

The bidding strategy for each generator of a generic *n-th* producer depends mainly on private information about costs, and considering that each producer owns more than one plant, he decides a "private merit order", on the basis of his capacity constraints, of his generation costs and of his power produced quantities, and therefore a "bids order" as a function of a chosen pricing strategy:

$$\left\{v_1^n, v_2^n, \ldots\ldots\ldots, v_{m^n}^n, \eta^{nj}\right\}$$

where η^{nj} is the set of estimated mean costs of other bidders *j*.

To define the expected surplus in an auction, it is necessary to consider all the outcomes that can occur in function of the realisation of demand η_D and of the merit order.

It is a good representation of behaviour of the producers to suppose that their objective is to maximise their own expected surpluses. For each bidder the expected surplus is expressed as:

$$E\left[S_n^G\right]=$$

$$=\left\{\sum_{u=1}^{i^n-1}\bar{p}_u^n\cdot\left[v_{i^n}^n-c_u^n\right]+p_{i^n}^n\left(\eta_D\right)\cdot\left[v_{i^n}^n-c_{i^n}^n\right]\right\}\cdot\Pr\left\{v_{i^n}^n\equiv v_{u_{\eta_D}}\equiv MCP\right\}\cdot\Pr\left\{\eta_D\right\}+$$

$$+\left\{\sum_{u=1}^{i^j-1}\bar{p}_u^n\cdot\left[v_{i^j}^j-c_u^n\right]\right\}\cdot\Pr\left\{v_{i^j}^j\equiv v_{u_{\eta_D}}\equiv MCP>v_u^n\right\}\cdot\Pr\left\{\eta_D\right\}$$ for $\forall i^n\in U^n$, $\forall i^j\in U^j$ and $\forall j\in J$.

As a first step, we suppose that the other producers submit a bid equal to their respective estimated mean cost ($v_u^j=\eta_u^{nj}$).

Hence, rivals' bids may be drawn from the cost distribution density function $f_u^{nj}\left(c\right)$. The expected surplus of producer *n-th* is expressed then as:

$$E\left[S_n^G\right]=$$

$$=\left\{\sum_{u=1}^{i^n-1}\bar{p}_u^n\cdot\left[v_{i^n}^n-c_u^n\right]+\right.$$

$$\left.+\left(\eta_D-\sum_{u=1}^{i_n-1}\bar{p}_u\right)\cdot\left[v_{i^n}^n-c_{i^n}^n\right]\right\}\cdot F_M^D\left(v_{i^n}^n\right)+$$

$$+\left\{\sum_{u=1}^{i^j-1}\bar{p}_u^n\cdot\int_{v_u^n}^{\bar{c}_{i^j}^j}\left[\hat{v}_{i^j}^j-c_u^n\right]\cdot d\left[F_I^D\left(v_u^n,i^j\right)\right]\right\}$$

for $\forall i^n\in U^n$, $\forall i^j\in U^j$ and $\forall j\in J$,

where $F_M^D\left(v_{i^n}^n\right)$ is the probability that the *n-th* producer is marginal with his i^n unit, while $F_I^D\left(v_u^n,i^j\right)$ is the probability that the i^n unit is a inframarginal unit when the MCP is set by i^j rival's unit, and they are defined as:

$$F_M^D\left(v_{i^n}^n\right)=\left\{1-\left[\sum_{i^j=i^n+1}^{U}\left[1-F_{i^j}^{nj}\left(v_{i^n}^n\right)\right]\right]-\left[\prod_{i^j=1}^{i^n-1}F_{i^j}^{nj}\left(v_{i^n}^n\right)\right]\right\}\cdot$$
$$\cdot\left[F_D\left(\sum_{u=1}^{i^n}\bar{p}_u\right)-F_D\left(\sum_{u=1}^{i^n-1}\bar{p}_u\right)\right]$$

$$F_I^D\left(v_u^n,i^j\right)=\left[1-F_{i^j}^{nj}\left(v_u^n\right)\right]\cdot\left[1-F_D\left(\sum_{u=1}^{i^j-1}\bar{p}_u\right)\right]$$

Solving the expression that maximises the expected surplus:

$$\frac{\partial E\left\{S_n^G\right\}}{\partial v_{i^n}^n} = 0$$

it is possible to find the function that represents the best bidding strategy for the i^n generator of the *n-th* producer:

$$v_{i^n}^n = \frac{\left[\left(\eta_D - \sum_{u=1}^{i^n-1}\bar{p}_u\right)\cdot c_{i^n}^n + \sum_{u=1}^{i^n-1}\bar{p}_u^n\cdot c_u^n\right]\cdot f_M^D\left(v_{i^n}^n\right)}{\left[\sum_{u=1}^{i^n-1}\bar{p}_u^n + \left(\eta_D - \sum_{u=1}^{i^n-1}\bar{p}_u\right)\right]\cdot f_M^D\left(v_{i^n}^n\right) - \left[\bar{p}_{i^n}^n\cdot\sum_{u=1}^{i^j-1} f_I^D\left(v_{i^n}^n, i^j\right)\right]} +$$

$$+\frac{-\left[\bar{p}_{i^n}^n . c_{i^n}^n\cdot\sum_{u=1}^{i^j-1} f_I^D\left(v_{i^n}^n, i^j\right)\right]}{\left[\sum_{u=1}^{i^n-1}\bar{p}_u^n + \left(\eta_D - \sum_{u=1}^{i^n-1}\bar{p}_u\right)\right]\cdot f_M^D\left(v_{i^n}^n\right) - \left[\bar{p}_{i^n}^n\cdot\sum_{u=1}^{i^j-1} f_I^D\left(v_{i^n}^n, i^j\right)\right]} +$$

$$+\frac{-\left[\left(\eta_D - \sum_{u=1}^{i^n-1}\bar{p}_u\right) + \sum_{u=1}^{i^n-1}\bar{p}_u^n\right]\cdot F_M^D\left(v_{i^n}^n\right)}{\left[\sum_{u=1}^{i^n-1}\bar{p}_u^n + \left(\eta_D - \sum_{u=1}^{i^n-1}\bar{p}_u\right)\right]\cdot f_M^D\left(v_{i^n}^n\right) - \left[\bar{p}_{i^n}^n\cdot\sum_{u=1}^{i^j-1} f_I^D\left(v_{i^n}^n, i^j\right)\right]}$$

3. Italian Electricity Market Analysis under Symmetric Information

In Italy, the generation available capacity is about 50 GW plus a 6000 MW of import capacity, and it is divided among various producers [15]. We divided the total capacity in a set of production mix as reported in table 1.

The aggregation of the production mix and the associate different production companies result in different configurations, some of which close to the actual situation or to possible future scenarios of the Italian electricity market, and capacity concentrations. We assume different scenarios characterised by a different number of producers. To each producer P_i are associated, in each scenario, different production mix as reported in table 2.

Table 1- Production mix for the Italian market (value in MW)

		PRODUCTION MIX							
		1	2	3	4	5	6	7	Total
TYPOLOGY	hydroelectric	4500	4500	400	500	100	800	2200	13000
	combined cycle	500	0	0	0	0	900	2800	4200
	oil	3000	3500	900	1100	0	0	300	8800
	oil–gas	1600	1600	2400	1800	1100	1300	2200	12000
	oil–coal	1800	1600	900	300	900	0	0	5500
	oil–coal–gas	800	800	0	0	0	0	0	1600
	diesel oil	0	0	0	100	0	0	300	400
	turbogas	1100	1200	300	0	0	400	200	3200
	TOTAL	13300	13200	4900	3800	2100	3400	8000	48700

Table 2- Production companies in the different scenarios considered

	PRODUCTION MIX							
	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**Import**
base case	P1 48,4%		P2 8,96%	P3 6,95%	P4 3,84%	P5 6,22%	P6 14,6%	IMP 11%
case 1	P1 48,4%		P2 40,6%					IMP 11%
case 2	P1 48,4%		P2 26%				P3 14,6%	IMP 11%
case 3	P1 24,3%	P2 24,1%	P3 26%				P4 14,6%	IMP 11%
case 4	P1 24,3%	P2 24,1%	P3 8,96%	P4 6,95%	P5 3,84%	P6 6,22%	P7 14,6%	IMP 11%

The present situation of the Italian market, that is underway of definition, is represented by the "base case". There is one prevalent production company which owns both M1 and M2, four GENCOs corresponding each to M3, M4, M5 and M6 mix each, and a set of municipal utilities lumped together in the M7 mix. In addition, an import from abroad of 6000 MW is considered. With respect to this situation, some additional cases are studied to illustrate the concentration impacts on market outcomes with different levels of symmetric information. The cases from 1 to 4 correspond to a decrease in the level of concentration: from duopoly (case 1) to the maximum level of disaggregation (case 4). In the cases 1 and 2 there is a dominant producer P1(M1+M2), while in the cases 3 and 4, the producer P1 is no longer dominant.

In table 3, for each power source typology, the total available capacity and the assumed production costs are shown. For sake of simplicity the hydroelectric and imports have been assumed with zero variable cost. Import is, as a matter of fact, nowadays an indispensable source to satisfy the total Italian demand.

Considering an average load for a work day (37,456 GW), we obtain the values of the MCP and the S^G, reported in the tables 4 and 5 for different value of σ_C that is expressed as percentage of the mean value of cost distribution.

Table 3- Production cost for different supply sources

Typology		Total capacity [MW]	Production costs [€/MWh]
Hydroelectric plants		13000	0.00
Combined cycle plants		4200	30.00
Traditional thermoelectric plants	Oil	8800	35.70
	Oil– gas	12000	39.90
	Oil – coal	5500	39.00
	Oil – coal – gas	1600	37.50
Diesel oil		400	84.00
Turbogas		3200	94.50
Import		6000	0.00
TOTAL		54700	

Table 4-Trend of the MCP for a hourly load of 37,456 GW

	MCP [€/MWh]				
σ_C [%]	**base case**	**case1**	**case2**	**case3**	**case4**
5	33,000	34,367	33,400	33,200	33,000
14	33,000	34,403	33,400	33,200	33,000
23	33,200	34,891	33,400	33,400	33,200
32	33,200	35,100	34,711	33,400	33,200
38	33,305	35,100	35,100	34,826	33,200

Table 5- Trend of the total S^G for a hourly load of 37,456 GW

	S^G [€]				
σ_C [%]	**base case**	**case1**	**case2**	**case3**	**case4**
5	605,700	674,048	630,560	618,080	605,700
14	605,700	675,224	630,560	618,080	605,700
23	618,080	691,036	630,560	630,560	618,080
32	618,080	695,591	685,228	630,560	618,080
38	673,593	695,591	695,591	690,144	618,080

We observe that increasing the number of producers and decreasing the capacity owned by each company (from case 1 to case 4), with the same level of symmetric information, it is possible to reduce the MCP and the Producer Surplus. The results show as in an oligopoly market prices are greater than in a perfectly competitive market [16].

Moreover, we observe that the MCP increases with producers uncertainty (σ_C increases). In fact, the revelation of information about the costs of the producers has the effect to decrease the importance of private information, and therefore to decrease the MCP and consequently the S^G. The uncertainty related to the reduction in the level of information leads to a generalised trend to fix higher bids. From table 4 and 5 we may note that the impact of information plays a different role with different market concentrations. In case 4, closer to perfect competition, the impacts in terms of MCP and S^G is lower while for highly concentrated markets (case 1) the impacts are more important.

It is interesting to notice that, in the case of symmetric information, the number of players is more relevant than their size uniformity. In fact the base case, characterised by a wide number of small producer facing a dominant producer, gives outcomes rather similar, both in term of price and of global surplus, than the competitive case. Also the effect of an increase in uncertainty is very low in both situations.

The incompleteness of the information connected to the uncertainty of load affects the MCP as depicted in Figure 1, in which it is shown how the MCP increases as the load σ_D increases.

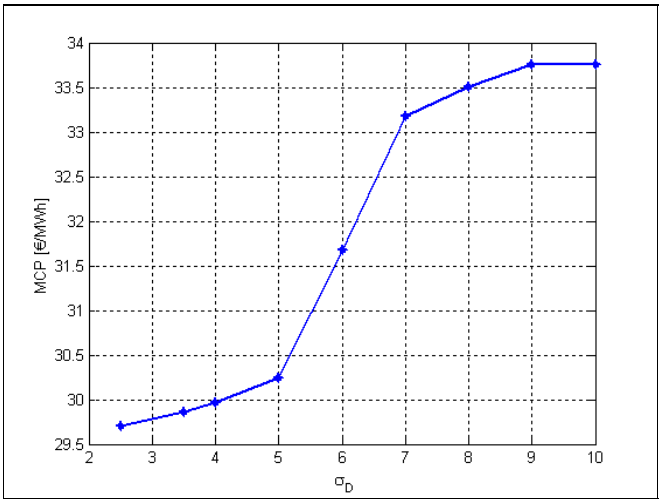

Figure 1- MCP as a function of σ_D

4. Effects of Asymmetric Information on Equilibria of Italian Electricity Market

We consider again the base case described in the previous section (table 2) to assess the impacts on the market outcomes of the asymmetry of the information among the market participants. This case may depict quite well a possible Italian electricity market.

The study of competitive markets under asymmetric information is particularly important because different market players may possess different information and this is the case of a former monopolist that, under liberalization, has been compelled to sell a certain amount of its generation capacity.

We consider three load levels and precisely a high load (46,349 GW), a low load (21,355 GW) and an average load (37,456 GW).

Our simulations show that, for the low and average load, the producers act almost as if they would be in a perfectly competitive market, submitting bids at their marginal production costs independently from the level of information they have, putting into evidence that in the conditions close to perfect competition the prices reveal the private information of any producer [16].

In the case of high load, with a mean value of 46,349 GW and a σ_D of 1,04 % which represents the error in the forecast for a typical week-day, we analyse, as a function of the information distributed among the players, the market outcomes, in terms of MCP and total producer surplus S^G, divided into expected producer surplus of dominant producer P1 S^G_{P1} and expected aggregate producer surplus S_r^G of producer P1's competitors. The expected aggregate producer surplus of rivals of producer P1 is defined as:

$$S_r^G = \sum_{j \in J} S_j^G = S^G - S_{P1}^G$$

For producer P1 an information level, measured by $\sigma_{C\text{-}P1}$, of the expected cost value of the competitors is considered, while a uniform information level, measured by $\sigma_{C\text{-}r} = \sigma_{C\text{-}P2} = \sigma_{C\text{-}P3} = \ldots\ldots = \sigma_{C\text{-}P6}$, is assumed for each competitor of P1.

Figure 2 reports the MCP as a function of $\sigma_{C\text{-}r}$ for $\sigma_{C\text{-}P1}$=10%. The first column ($\sigma_{C\text{-}r}$=10%) represents the symmetric case in a situation of high load. Even in this case, the uncertainty connected to uniform information level of competitors violates one of the hypotheses of the perfect competition leading to a MCP increase with respect to this ideal case. As far as $\sigma_{C\text{-}r}$ grows, MCP grows too, showing that asymmetry represents a further worsening in the consumer position.

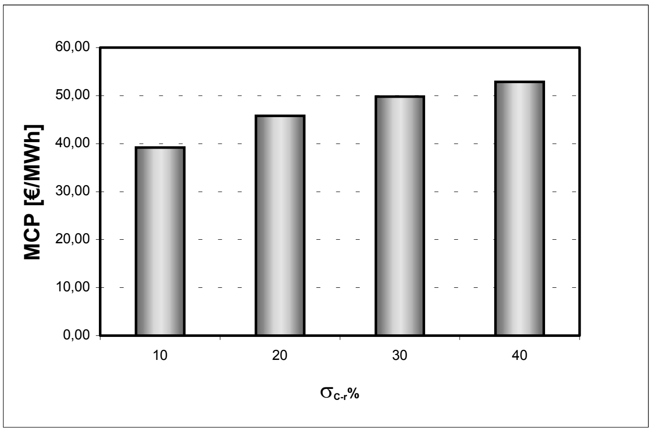

Figure 2-MCP as a function of $\sigma_{C\text{-}r}$ for $\sigma_{C\text{-}P1}$ =10%

Asymmetry in information gives further incentives, respect to the symmetric case with incomplete information, to fix bids more and more diverging from the marginal cost. In this simulation, for the symmetric case ($\sigma_{C\text{-}r}$=10%) the marginal cost of the last dispatched generator is 37 €/MWh , while the MCP is 39.2 €/MWh, with a 5% surcharge. In the case of maximal asymmetry ($\sigma_{C\text{-}r}$=40%)

the marginal cost remains nearly unchanged (36.9 €/MWh), while price grows up to 52,8 €/MWh, with a mark-up of 43%.

In Figure 3 we represent the expected global producer surplus with different information levels of P1's competitors, and its division between P1 and other producers. First of all we see that an increase in asymmetry causes an increase in global producer surplus, which goes at the expenses of consumers. For a given information level of the producer P1 ($\sigma_{C\text{-}P1}$=10%), we register a parallel increase of P1 and competitors' surplus. This is a counterintuitive result, because it is shown that even the competitors can earn from asymmetry in information, with a huge worsening of the consumer position. This is mainly due to the global worsening in the level of information kept by the players that causes a MCP increase. Anyway P1's surplus increases more steadily and becomes, as soon as we go away from the situation of symmetric information, greater than the one earned by the competitors. This means that asymmetry causes a shift of benefits from the competitors to P1.

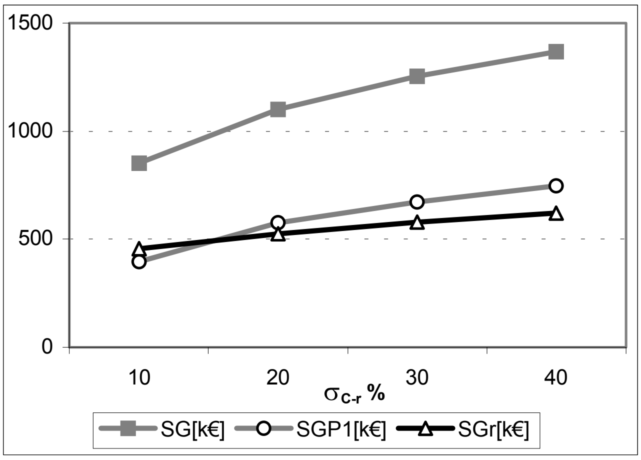

Figure 3-Expected producer surpluses as a function of $\sigma_{C\text{-}r}$ for $\sigma_{C\text{-}P1}$ =10%

This becomes clearer observing Figure 4 which shows the distribution of S^G. A decrease of the information level of his competitors ($\sigma_{C\text{-}r}$ increases) causes an increase in the share of expected surplus of P1, putting into evidence an advantage to P1 due to his higher level of information. For example, assumed $\sigma_{C\text{-}P1}$=10%, we have an expected surplus of the producer P1 equal to 396.350 € for $\sigma_{C\text{-}r}$ =10% and equal to 747.227 € for $\sigma_{C\text{-}r}$ =40%.

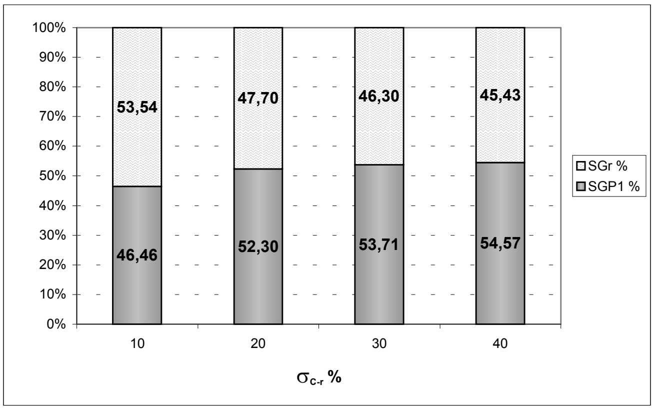

Figure 4-Distribution of S^G between producer P1 and his competitors as a function of $\sigma_{C\text{-}r}$ for $\sigma_{C\text{-}P1}$ =10%

In the symmetric situation, the dominant producer is able to obtain a share of load (50,8%) greater than its share in capacity (48,4%, table 2). This means that he can influence, thanks to the high number of plants owned that allow multiple bidding strategies, the probability to get his plants dispatched. This situation of market power is not reflected by the share of surplus earned by P1 (figure 4), which is still lower than the one earned by other producers and than the share in production and capacity. Passing to $\sigma_{C\text{-}P1}$=20% the dominant producer is still able to get some more generators dispatched, at the expenses of other producers' share in generation, going down to 47.7%. From there on market shares in terms of generation remain stable and the increase in P1 share in surplus is only caused by its capacity to earn higher margins on its costs.

5. Conclusions

We have proposed a model based on the IPV auction theory to assess the impacts of information on electricity markets, based on a centralised pool for market clearing. The model has been used to study the market outcomes in different information contexts with reference to the Italian situation.

Information plays a major role in determining the market outcomes in terms of prices and surpluses.

In a symmetric information context, an increase in the level of information, giving to all the producers sharper knowledge about competitors' production costs, has the effect to decrease the importance of private information, and therefore to decrease prices and the expected surplus of each producer with benefits for the consumers. The effect is more marked in the markets with high concentration of the capacity and becomes less important with an high level of competition. Information diffusion and sharing in the markets among the players would be, in this respect, appropriate. In fact the market inefficiency due to scarce transparency is paid by the consumers in terms of higher prices.

The incompleteness of the information connected to the load uncertainty in the day-ahead market strives for an increase in prices; more the load forecast is accurate, more the impact of the associated uncertainty is negligible.

In an asymmetric information context, for a given information level of the dominant producer, an increase in asymmetry causes an increase in prices and in the global producers' surplus, which goes at the expenses of consumers. In this situation both P1 and the competitors seem to benefit from asymmetry, because they show growing surpluses as far as $\sigma_{C\text{-}r}$ increases. Anyway P1,which possesses an informative level higher than those of the competitors, is able to increase his own producer surplus more, at the expenses of those obtained by the competitors. This effect too may damage the consumers in the long run, since it may represent a counterincentive for new players entering in the market, while a reduction in concentration is highly desirable for its effect in price reduction and in smoothing the effects of market imperfections.

Further work in underway to include in the model the demand side bidding and to develop a more detailed representation of the information sets of the producers.

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