Price capping in partially monopolistic electricity markets

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Abstract

In this paper we consider an oligopolistic market in which one firm can be monopolist on her residual demand function and derive implications on the shape of her profit function, which we show may not be concave in price. We propose a simple price-capping rule that induce the *pivotal* operator to compete for quantity instead of taking advantage of her monopoly. Then, we analyze the bidding behaviour of the dominant electricity producer operating in the Italian wholesale power market (IPEX). This firm is vertically integrated and in many instances she acts as a monopolist on the residual demand. We find that, contrary to expectations, this pivotal firm refrains to exploit totally her unilateral market power and, therefore, bids at levels well below the cap. We discuss such a behaviour and derive implications for the setting of the price cap.

Keywords: Electricity auctions, capacity constraints, price cap, optimal bidding
JEL: C50; L11; L12; L43; L51; L94; Q41; Q48

1. Introduction

There is a growing body of literature that analyses electricity markets at both theoretical and empirical level. Wholesale electricity markets

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can be modeled as multi-unit auctions where multiple identical objects are bought/sold and demand/supply is not restricted to a single unit. From the theoretical point of view, the analysis concentrates mainly on the properties of the market design (various possible auction formats) and on the strategic behavior of auction participants whereas the main focus of applied researchers is on the estimation of firms' market power.

From a theoretical point of view, like other cases of auctions for identical and divisible objects – such as Treasury Bills – electricity auctions are often analyzed as quota or share auctions. Ausubel and Cramton (2002), following the line of research first introduced by Wilson (1979), found that when multiple units are sold simultaneously under the uniform price rule, buyers have an incentive to "shade" their demand (reduce their valuation) for all units following the first. In this manner they optimally trade-off a lower probability of winning on the last units against savings on all units bought. Electricity markets, in which the majority of sellers own a number of generating units, show the same type of incentives on the supply side because overbidding on the last units increases the revenues for all the inframarginal units despatched in equilibrium. This is easy to understand since in a multi-unit auction with uniform price rule a high price is a public good. A similar (bid shading) result was obtained by Parisio and Bosco (2003, 2008) who relaxed the assumption of costs common knowledge and derived equilibrium bid functions in both isolated and interconnected electricity markets [1]. They show that the extent of bid shading, and therefore the mark-up, depends among other things upon the endowments of generation capacity of each multi-plant firm. Hortaçsu and Puller (2008) characterize the bidding behavior of electricity generators within the theoretical framework of Wilson's share auction. Before them, Wolak (2003) used a similar model of bidding behavior to recover cost function estimates for electricity generation in the Australian National Electricity Market. He shows that under the assumption of firm-level profit maximization, it is possible to estimate the level of marginal costs implied by a given equilibrium price and quantity. Observed bid data can be used to compute directly the Lerner Index of market power.

The finding that firms fail to exploit the full potential of market power in electricity markets is a quite common result in the applied literature. One possible explanation of this apparently suboptimal behavior relies on the fact that firms may be vertically integrated which means that they may be

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[1] Many researchers have implemented and refined this model, for example, Brunekreeft (2001), Garcia-Diaz and Marin (2003), Fabra (2003), Fabra *et al.* (2006).

active on both sides of the auction. Bushnell *et al.* (2008) analyses theoretical and empirical implications of firms that act both as buyers and sellers in electricity auctions. In their model Cournot equilibrium can produce prices lower than perfectly competitive ones when vertical arrangements are considered. To the extent that large producers also have even larger retail obligations, they may find it profitable to overproduce in order to drive down their wholesale costs of power purchased for retail services. When the firm is a net buyer marginal revenue is greater than price and therefore it is profit maximizing to produce at levels where marginal costs is greater that prices. Bushnell *et al.* (2008) found that the vertical relationships between producers and retailers play a key role in determining the competitiveness of the spot markets they analysed (California, New England, and PJM). Their findings support Wolak's (2000) analysis of the effects of long-term contracts in the Australian electricity market, as well as Fabra and Toro's (2005) results for the Spanish market. Also Wolak (2010) emphasises that a supplier's incentive to exercise unilateral market power can differ dramatically from its ability to exercise unilateral market power. This is due to the presence of fixed-price forward market obligations: only a supplier who expects to sell more than its fixed-price forward market obligation in the short-term market has an incentive to use its ability to exercise unilateral market power to raise the short-term price. In this paper we contribute to the above literature by exploring another possible cause of the lack of market power exploitation. Assume that under high demand conditions a producer is indispensable for the equilibrium even if all the competitors' offered at their maximum capacity. In this case, that *pivotal* bidder should in theory offer at a price equal to infinity (or at the cap). This in turn implies that his optimal profit function should exhibit some non-concavity when the price reaches the level at which competitors exhaust their capacity. Beyond that point the residual demand becomes constant and coincides with the market demand which can be served by the *pivotal* bidder at almost any price. We explore this case and derive implications for the bidding behaviour. The paper is organised as follows. In Section 2 we discuss bidding behaviour in electricity auctions and derive the condition for profit maximising behaviour without imposing any restriction on demand conditions. In Section 3 we present a model for the above described *pivotal* bidder and show, also with a numerical example, how demand conditions can affect the shape of his profit function for different levels of price. In Section 4 we first describe the main characteristics of the Italian electricity market and then we use data generated on that market to test the hypothesis that profit functions may become non-concave when the demand level is high. Section 5 concludes.

2. Optimal bidding strategies, pivotal bidders and price capping policy

Theoretical and applied analyses of wholesale electricity markets are based on two alternative strategic models of bidding behaviour, namely the Wilson's Share auction model (Wilson, 1979) and the Supply function equilibrium (SFE) model of Klemperer and Meyer (1989). The former is based on the assumption that bidders are uncertain about private characteristics of rivals (e.g. costs, forward contract position) and about demand level, whereas in the latter only demand is ex-ante uncertain to bidders while costs level are known. However, under a set of simplifying assumptions the FOCs for an optimal bid/supply function coincide in the two models. Whatever the source of uncertainty that characterises the two approaches, it results into randomness of the residual demand facing each bidder and therefore it is the distribution of the residual demand that is relevant in the optimal strategy calculation. Other simplifying assumptions, that are frequently invoked by both lines of research, are linear and price-inelastic demand and constant marginal costs. The optimal supplies of bidders, namely the optimal quantity to be offered at each possible equilibrium price level, are restricted to be continuously increasing differentiable functions. Both auction and SFE models assume that the aggregate firm capacity is larger than the maximum possible level of demand and that there are not pivotal suppliers. A supplier is said to be pivotal if he/she is able to set the price in the auction by withholding some portion of its production from the market. It has been recognised that pivotal suppliers are most likely when demand is near the peak, when the market capacity is limited relative to peak demand ad/or when firms capacities are unevenly distributed. One interesting case emerges when there is only one firm that is pivotal: this happens when all rival firms' capacity is insufficient to meet demand with positive probability. In this case the pivotal firm is able to set the market price at the maximum allowed value (infinity or at the cap) by witholding its output at prices below that value[2]. The incentive to bid at the highest possible price level for pivotal suppliers is a result common to both auctions and SFE models.

Consider first N multi-plant firms competing in a day-ahead market to get the right to supply electricity at price p^e which is the uniform price to be paid to all units called into operation. Total demand is $\hat{D} = D + \varepsilon$, where ε

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[2]For this reason regulators frequently calculate the so-called residual supply index RSI as the ratio of residual supply to the total demand. In an applied analysis Sheffrin (2001) showed that the average price-cost markup goes to zero for a RSI equal to 1.2.

is a purely random shift component. Each bidder has costs given by $C_i(q)$, $i = 1, \ldots, N$, for which the hypothesis of private value holds. Auctions take place on an hourly basis and we treat each hour as an independent auction. Bidders submit supply schedules $q = y_i(p)$ that indicate the optimal quantity offered at price level p. We assume supply schedules y_i, $i = 1, \ldots, N$, to be strictly increasing and continuously differentiable.

From the point of view of bidder i, the equilibrium price p^e is determined where his supply function $y_i(\cdot)$ intersects its residual demand, namely

$$y_i(p^e) = \hat{D} - \sum_{\forall j \neq i} y_j(p^e)$$

As a consequence, the probability distribution of the market clearing price, conditional on the supply $y_i(\cdot)$ can be written as:

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\begin{aligned}
H\big(p, y_i(p)\big) &= \Pr\left\{ p^e \leq p | y_i(p) \right\} \\
&= \Pr\left\{ y_i(p) \leq \Big[\hat{D} - \sum_{\forall j \neq i} y_j(p) \Big] \right\}
\end{aligned}
$$

Then, $\forall p$ and $y(p)$, $H(\cdot, \cdot)$ is a probability distribution generated by $y_j(p)$, $\hat{D}$ and N. We assume that H is differentiable in p and $y(\cdot)$. The assumption that each $y(\cdot)$ is a strictly increasing function implies that H has a continuous support $[\underline{p}, \overline{p}]$.

Following Bushnell *et al.* (2008) we also assume that at least some of the bidders are vertically integrated firms. This means that they may be simultaneously sellers and buyers which means that firms may have an upstream generator and a downstream firm that performs the retail activity. We can assume that the quantity bought for retailing in the electricity auction is fixed (due to long term obligations), let it be x_i, and that it will be sold at a predetermined price p^r.

The expected profit of bidder i can be written as:

$$\mathbb{E}\left[\pi_i\right] = \int_{\underline{p}}^{\overline{p}} \left[p^e y_i(p^e) - C_i\big(y_i(p^e)\big) + (p^r - p^e) x_i \right] \mathrm{d}H \tag{1}$$

Equation (1) may be rewritten in variational form as follows:

$$|K| - \int_{\underline{p}}^{\overline{p}} \left\{ \big(y_i(p^e) - x_i \big) + p^e y_i'(p^e) - C_i'\big(y_i(p^e)\big) y_i'(p^e) \right\} H\big(p^e, y_i(p^e)\big) \, \mathrm{d}p^e$$

where K is a constant. Euler's equation generates an optimal $y_i^*(p^e)$ such that:

$$p^e = C_i'\big(y_i^*(p^e)\big) + \big(y_i^*(p^e) - x_i\big) \frac{H_{y_i}^i\big(p^e, y_i^*(p^e)\big)}{H_{p^e}^i\big(p^e, y_i^*(p^e)\big)} \tag{2}$$

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The numerator on the rhs measures the shift in the probability distribution of the market clearing price due to a change in the supply of bidder i and the denominator is the density of H. Using our definition of H and the assumptions about $y(.)$ it is possible to derive a manageable expression for the probability ratio in (2), as follows[3] :

$$p^e = C_i'\big(y_i^*(p^e)\big) + \frac{y_i^*(p^e) - x_i}{\frac{\partial}{\partial p^e} \sum_{\forall j \neq i}^N y_j(p^e)} \tag{4}$$

Let $RD_i(p) := \hat{D} - \sum_{\forall j \neq i}^N y_j(p)$ be the residual demand facing bidder i. Then, under the assumption of price-inelastic total demand, $RD_i'(p) := -\frac{\partial}{\partial p} \sum_{\forall j \neq i}^N y_j(p)$. Equation (4) can be transformed into a Lerner Index where the inverse elasticity of the residual demand net of quantities bought measures the incentive a firm has to withhold output in order to raise the short-term market price (large positive value) and to increase output in order to lower short term market price (large negative value).

$$\frac{\big(p^e - C_i'\big(y_i^*(p^e)\big)\big)}{p^e} = \frac{(RD_i - x_i)}{p^e RD_i'(p^e)} \tag{5}$$

Equation (5) measures the incentive to use market power when a firm is vertically integrated. If only the production side of the firm is considered (or if the firm does not act as a buyer on the demand side of the power market), then x_i is equal to zero and the Lerner index would increase. Therefore we expect that a vertically integrated firm has less incentive to use his market power with respect to a firm who only sells in the market. Due to vertical integration, the numerator on the rhs of (5) could also be negative. This happens when the firm is a net buyer on the market. A profit maximising net buyer has the incentive to reduce the equilibrium price which results to be lower than marginal costs. We therefore conclude that a vertically integrated bidder can be subject to a very different type of incentives depending on its

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[3]Under the same set of assumptions and with full knowledge of bidders' costs, SFE models provide conditions for supply functions $y_i(p)$ of firm i such that the clearing price p maximises profits $\Pi_i(p, \hat{D})$ for each possible demand realisation and with $y_i(p) = \hat{D} - \sum_{\forall j \neq i}^N y_j(p)$. The optimal bid function is the solution to a system of ordinary differential equations:

$$\sum_{\forall j \neq i}^N \frac{dy_j(p)}{dp} = \frac{y_i(p)}{(p - C_i')}, \ i = 1, ..., N \tag{3}$$

It is evident from (4) and (3) that SFE and Share auction models produce the same set of conditions for optimality.

net position of the market. This in turn will have effect on the shape of its profit funtion, as we will consider in the next section.

3. Capacity constraints and the pivotal bidder

Now suppose that i is the pivotal supplier and that the total demand cannot be satisfied even if all competitors of i offer their total capacity. This implies that there is a price, say $\bar{p}$, above which the residual demand faced by i equals a positive constant, say $\overline{RD}$:

$$RD_i(p) := D - \sum_{j \neq i} S_j(p) = \overline{RD} > 0, \qquad \forall p > \bar{p}.$$

As a consequence, the derivative $\frac{d}{dp} \sum_{j \neq i} S_j(p)$ in equations (4) and (3) equal zero for $p > \bar{p}$ and the optimal bidding solution for i is to offer (part of) its electricity at price $p = \infty$. This simple result underlines the importance of some price capping mechanism in electricity markets with a pivotal supplier.

In order to understand how the price cap should be chosen, let us consider the profit function of the pivotal supplier i:

$$\pi_i(p) = \begin{cases} RD_i(p) \cdot p - C\big(RD_i(p)\big), & \text{for } p < \bar{p}, \\[2mm] \overline{RD} \cdot p - C(\overline{RD}), & \text{for } p \geq \bar{p}. \end{cases}$$

The shape of this curve for $p < \bar{p}$ depends on the assumptions on how the residual demand and cost functions behave in that interval, but for $p \geq \bar{p}$, the profit curve is just a straight line with slope $\overline{RD}$: the larger the residual demand that cannot be satisfied by the competitors, the faster the pivotal supplier's profit increment. Notice that for $p < \bar{p}$ the profit function is the usual one, so under standard conditions it will be concave. As described in the previous Section we expect that since vertical integration modifies the exposure of the firm to the market price, then it would influence the shape of the profit function. In this case the profit funtion of the pivotal supplier would become:

$$\pi_i(p) = \begin{cases} (RD_i(p) - x_i) \cdot p - C\big(RD_i(p)\big) + p_r \cdot x_i, & \text{for } p < \bar{p}, \\[2mm] \big(\overline{RD} - x_i\big) \cdot p - C(\overline{RD}) + p_r \cdot x_i, & \text{for } p \geq \bar{p}. \end{cases}$$

where p_r is the (regulated) selling price for the quantity bought x_i. Therefore a supplier can be pivotal and so he can be able to raise substantially the market price but at the same time he could have a little incentive to exploit

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its pivotal status. This happens when the firm is not net pivotal, namely when $(\overline{RD} - x_i) < 0$. In this case the pivotal quantity $\overline{RD}$ is less than the bought quantity x_i.

We can illustrate the behaviour of the profit function with a numerical example. Hypothetical profit functions of the pivotal supplier are plotted in Figure 1. These curves are fictional, but an actual profit curve may be estimated using real auction data and the cost function of the pivotal producer.

The plots in Figure 1 are based on the hypothetical pivotal supplier's cost function

$$C(q) := 30 + 200 \left(\frac{q}{20000} \right)^2,$$

and on the three following competitor's aggregate supply functions

$$S_1(p) := \min \left[40000, 45000 \left(1 - 1/(1 + 0.1p^{0.9}) \right) \right], \quad \text{(continuous blue line)}$$
$$S_2(p) := \min \left[40000, 50 + 5000\sqrt{p} \right], \quad \text{(dotted red line)}$$
$$S_3(p) := -40000 + 80000/(1 + e^{-p/20}). \quad \text{(dashed green line)}$$

Cost and supply functions are depicted in Figure 2. As already noticed, these figures are artificial, but quantities should be thought as MWh and prices and costs as Euros. A total competitors' capacity of 40000 MWh has been supposed for all three supply functions.

The three subplots in Figure 1 refer to the following demand levels: 40000 (low demand, dominant supplier not necessary), 42000 (mid demand, monopoly on 2000 MWh), 50000 (high demand, monopoly on 10000 MWh).

By observing Figure 1a, we see that when the dominant supplier is not necessary for satisfying the total demand, she maximizes her profits by trying to serve a share of the demand by competing on prices. On the contrary, when the demand cannot be entirely satisfied by the competitors of the dominant supplier (Figure 1, panels b and c), then the latter maximizes her profit by selling the residual demand $\overline{RD}$ at infinite price. In the presence of a vertically integrated pivotal supplier we expect that the profit funtion would lose part of its linear increasing portion and would become more similar to a standard concave profit function.
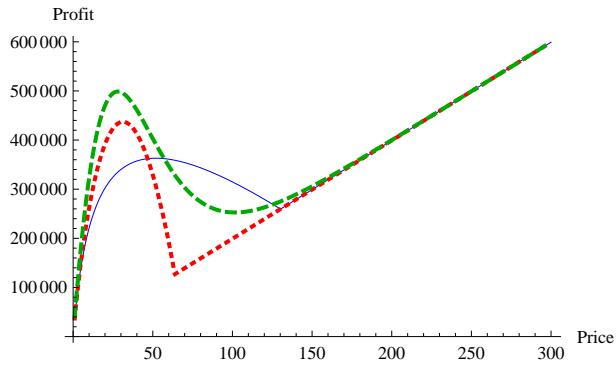
In this setup, a regulator could force the pivotal supplier to compete with the other suppliers by fixing a price cap that satisfies

$$\begin{cases} \pi(p_c) < \max_{p \leq \bar{p}} \pi(p), \\ p_c \geq \bar{p}, \end{cases}$$
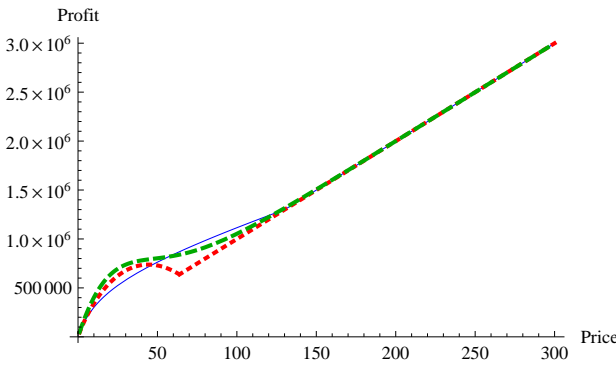
where $\bar{p}$ is the price above which $RD(p) = \overline{RD}$ and p_c denotes the price cap. The first condition identifies all the prices for which the profit of the pivotal

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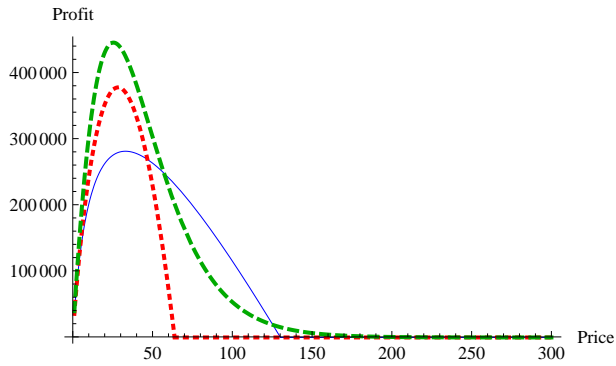
Figure 1: Hypothetic profit curves of the pivotal supplier as functions of price.
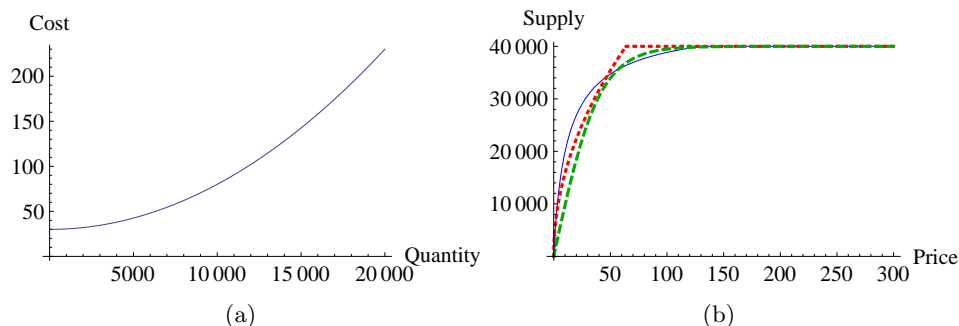
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Figure 2: (a) cost function of the pivotal supplier, (b) competitor's aggregate supply functions.

supplier is not greater than the maximum profit under competition. This condition makes competition more convenient than monopoly, since fixing the price at the cap would lower profits. The second condition identifies all prices in which the pivotal supplier is exploiting its partial monopoly, which is the condition under which a price cap should intervene. Unfortunately, in some cases in which the monopolistic residual demand is very high, a price cap satisfying the two conditions above may not exist.

Figure 3 illustrates how a price cap respecting the two above conditions can be chosen. For this example we use the competitors' supply function $S_1(p)$, and two different level of monopolistic residual demand: $\overline{RD} = \{2000, 10000\}$. We see that when the monopolistic residual demand is not too high as in panel (a), there are infinitely many price caps that will work. On the contrary, if the demand that cannot be satisfied by the competitors is very large, then the profit function may become strictly increasing and there is no price cap that is able to foster price competition. In this case the pivotal supplier will always bid the price cap, and this could be reasonably fixed at $p_c = \bar{p}$.

4. Application to the Italian electricity market

4.1. The Italian electricity market

In this section we introduce the main characteristics of the Italian electricity industry and then we analyze the market rules of the Italian wholesale electricity market (IPEX).

IPEX started its operations in April 2004 with bidders acting on the supply side only. The demand side of the market became active since January
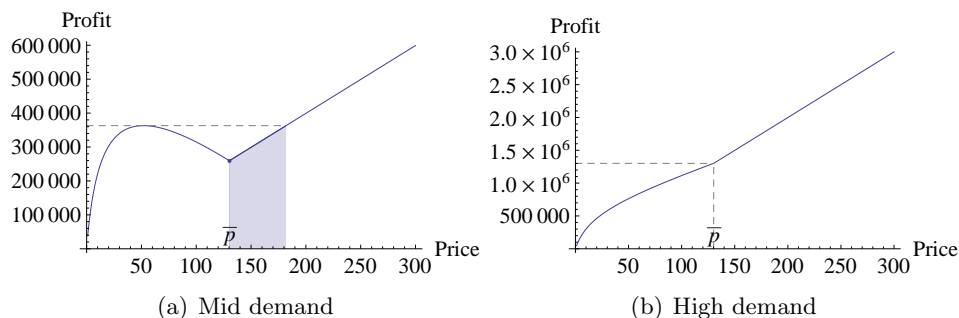
(a) Mid demand   (b) High demand

Figure 3: Price cap choice: (a) all the prices in the shaded area respect the price cap conditions, (b) no price cap can foster price competition. $\bar{p}$.

2005. Since then the participation[4] in the IPEX markedly increased: in the year 2008 there have been 81 operators on the supply side and 91 operators on the demand side. In the same year, the volume of energy exchanged amounted at 232 TWh with a liquidity rate of the 69%. Before liberalization the Italian electricity industry was dominated by a state-owned monopolist (Enel) that controlled all the stages of activity, from generation to final sale. By the time the sector was opened to competition a portion of generation capacity previously controlled by Enel has been sold to newcomers with the intention of creating a more leveled playing field. In Figure 4 we present data on market share for years 2007 and 2008.

The increased number of operators in the IPEX did not have much influence on wholesale prices. On the contrary, electricity prices showed an increasing trend. Table 1 reports annual averages for different time slots like peak, off-peak. holidays, etc.

Table 1: Mean wholesale electricity prices (Euros)

	2005	2006	2007	2008
Total	58.59	74.75	70.99	86.99
Week day	64.98	81.43	76.48	91.06
Peak	87.80	108.73	104.90	114.38
Off peak	42.15	54.12	48.06	67.75
Holidays	44.33	60.25	58.58	77.88

[4]Data are taken from the last report published by the GME in 2009, "Annual report 2008".
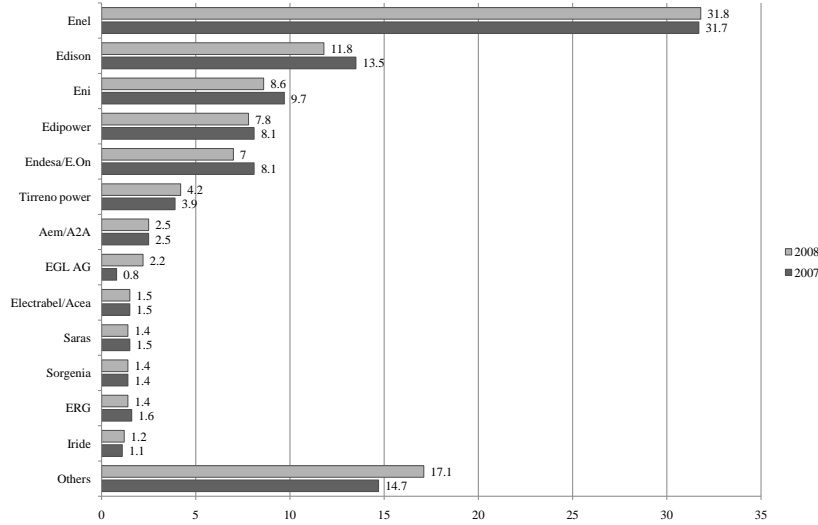
Figure 4: Market shares of electricity producers

The comparison between the Italian market and other European markets show that there exists a significant gap between Italian prices and other European prices[5].

The IPEX is composed by a day-ahead market (MGP), an Infra-day market and an ancillary services market (MSD). MGP operates as a daily competitive market where hourly price-quantity bids are submitted by generators and by buyers. The market operator (GME) orders bids according to a cost reducing merit order for supply and in a willingness to pay order for demand. The market equilibrium is calculated in the intersection of supply and demand. The resulting equilibrium price (SMP) is paid to all despatched suppliers. When MGP determines an equilibrium price and a corresponding equilibrium quantity that are compatible with the capacity constraints of the transmission grid – both "nationally" and locally – the wholesale electricity trade is completed. On the contrary, if the volume of

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[5]For a cointegration analysis of the prices of the main European electricity markets see Bosco et al. (2010)

the electricity flow determined in the MGP exceeds the physical limits of the grid and in some areas congestions occur, a new determination of zonal prices must be obtained in order to eliminate congestion in those areas. To this end the GME uses the bids submitted at the MGP by the generators located in the congested areas to compute a specific merit order valid for those zones. Then he allows a flow of electricity in and out of those zones within the limits given by the transmission capacity and determines a specific zonal equilibrium.

4.2. A price capping rule for Italy

Since the first operations of the IPEX in April 2004, the Italian day-ahead market rules impose a price cap of 500 Euro/MWh for all plants bidding in the power exchange. In this section we try to apply the price capping rule proposed in Section 3 to the Italian market, in order to assess if the actual price cap is well-grounded or should be revised.

In the previous section we have seen that the largest operator in the Italian market is Enel. The total capacity of Enel's competitors cannot satisfy the aggregated Italian electricity demand in most o the auctions. Thus, the first step we have to go through is the construction of a good approximation of Enel's cost function in any given auction. At the moment of writing, Enel runs over 600 power plants: 37 are thermoelectric (hydrocarbon-based), 534 hydro, 20 wind-based, 2 photovoltaic and 30 geothermal[6]. Now, since renewable energy sources have negligible variable costs (approx. zero marginal costs), we concentrate just on the 37 thermal plants.

Thanks to Ref (Ricerche per l'economia e la finanza)[7], which gave us access to some of the data that feed their *Elfo++* system for the simulation of the Italian electricity market, we can derive the cost function for every thermal plant in Italy. In particular, the cost function of the production unit j is defined by the quadratic function

$$C_j(Q) = \sum_i \kappa_i \alpha_{ij} (c_{2ij} Q^2 + c_{1ij} Q + c_{0ij}), \tag{6}$$

Q is the generated power in MW, κ_i is the hourly price in Euro/Gcal of fuel i, $\alpha_{ij} \in [0, 1]$, such that $\sum_i \alpha_i = 1$, is the fraction of fuel i used by the plant j and $c_{2ij}, c_{1ij}, c_{0ij}$ are, technical coefficients that characterize the quadratic cost function of plant j with respect to fuel i; their unit of measurement

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[6]Source: `www.enel.it`

[7]`http://www.ref-online.it/`

is, respectively, Gcal/MW^{2}h, Gcal/MWh and Gcal/h. The index i ranges over the values $\{1, 2\}$ since the maximum number of fuels used in the plants is two. The fuel costs κ_i are, of course, time-varying, and we approximate their values, which usually depend on forward contracts, with their means over a month. It is straightforward to check, by simplifying the various unit of measurement in equation (6), that $C_j(Q)$ is measured in Euro/MWh. The information about the plant is completed by the pair $\{\underline{Q}_j, \overline{Q}_j\}$, which identifies the minimum and maximum power that the production unit j can supply.

The aggregate cost function of the whole set of n thermal plants is given by

$$C(Q) = \min_{Q_1, \ldots, Q_n} \sum_{j=1}^{n} C_j(Q_j)$$

such that $\sum_{j=1}^{n} Q_j = Q$ and $\underline{Q}_j \leq Q_j \leq \overline{Q}_j$ for $j = 1, \ldots, n$. This constrained optimization problem can be solved by using quadratic programming algorithms.

In order to build a cost function for a given auction, we merge the ELFO++ database with that published by the market operator (GME) whose detailed content is displayed in Table 2. We use the GME auction data for determining the quantity of electricity Enel is offering though non thermal units, and we compute the aggregate cost function using only thermal plants whose capacity is actually offered in the auction.

Now we are able to draw the (ex post) profit function of Enel for any auction. Notice that, since actual supply curves are constrained by the auction rules to be step functions, the profit curve will not be as smooth as those depicted in Section 3. Moreover, as we have no information on the (hourly) fixed costs that Enel supports, our estimation of the profit function is valid up to an additive constant. This is really not a limitation for our analysis, since we are interested in the shape of the profit function rather than in its level.

The plots in Figure 5 depict the profit function of *Enel Produzione*, the electricity generation company of Enel (left panel), and of the vertically integrated group that comprehend *Enel Produzione* and *Enel Trade* (from now on *Enel Group*), which is the company that buys energy on the electricity market for Enel (right panel). The system marginal price (SMP) is represented as a dashed vertical line and the auction the plots refer to (2nd December 2008 at 6pm), is the one with highest demand among all auctions of December 2008. The shape of the first plot clearly resembles those in the last panel of Figure 1. The most expensive offer by Enel's competitors

Table 2: Relevant fields in the Italian electricity auctions database[†].

Producer (seller)	Retailer (buyer)
Operator name	Operator name
Plant name	Unit name
Quantity (MWh) of each offer	Quantity (MWh) of each bid
Price (Euro) of each offer	Price (Euro) of each bid[††]
Awarded quantity (MWh) for each offer	Awarded quantity (MWh) for each bid
Awarded price (MWh) for each offer	Awarded price (MWh) for each bid
Zone of each offer (plant)	Zone of each bid (unit)
Status of the offer: accepted vs. rejected	Status of the bid: accepted vs. rejected

[†] Notice that in the GME database the producer's (seller's) bid is named *offer*, while the retailer's (buyer's) bid is called *bid*.

[††] The willingness to buy at any price is coded as zero.

coincides with a price of 250 Euro, so the application of our price-capping rule would suggest a price cap of 250 Euro. On the other hand the quantity offered by Enel's competitors for a price above 160 Euro is less than 4% of the their total offered quantity, and some 2% of the aggregated demand, so it would be interesting to find out if these offers correspond to very expensive plants or are just a way to "try the luck".

We derive the Enel Group profit function (π_G) using the actual quantity (x) bought by Enel Trade in the same auction:

$$\pi_G(p) \propto \pi(p) - p \cdot x.$$

If we concentrate on the second panel of Figure 5, we see that the profit function of the Enel Group is closer to those in the second panel of Figure 1 and the actual price cap of 500 Euro lies in the interval of the admissible price caps. Harder to explain is distance between the the SMP (160 Euro) and the optimal price for Enel (77.6 Euro).

Under low demand conditions the profit functions of Enel Produzione and Enel Group are those represented in Figure 6. The left-hand-side plot is similar to those of panel (a) of Figure 1, while the plot on the right is non-increasing. In this case Enel is not necessary for market clearing and, therefore, there is no need of a price cap. The SMP (41.7 Euro) is closer to the profit maximizing price for Enel, which would be 15 Euro. On the
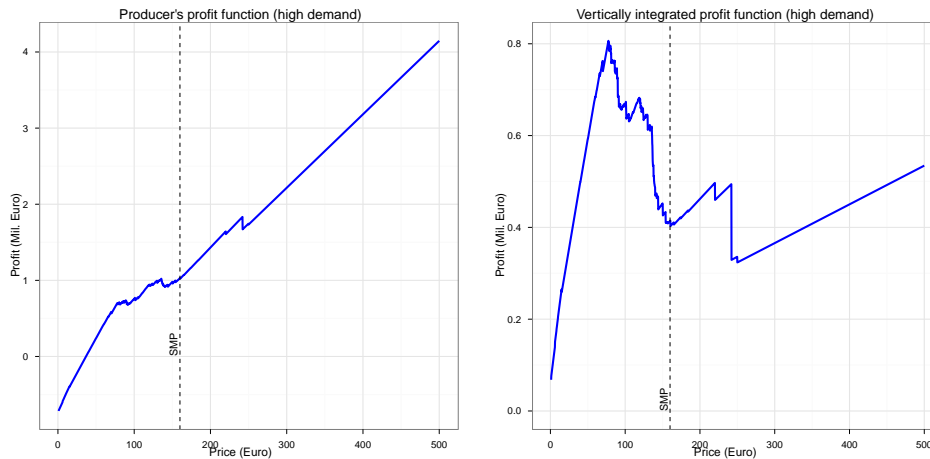
Figure 5: Profit function of Enel Production and of the Enel Group (vertically integrated). Auction: 02.12.2008:18 (peak)

contrary, if Enel were a pure generator, then its profit optimizing price would be 70 Euro.

We conclude this analysis by comparing Enel's marginal cost function with Enel's actual supply function as submitted to the high demand auction of 2nd December 2008 at 6pm. Figure 7 shows these two curves and also the average cost function, which, however, is a less reliable estimate of the real average cost because of our uncertainty about fixed costs. The great market power of Enel is apparent from the remarkable vertical distance between the supply curve and the marginal cost function.

5. Conclusion

Wholesale electricity markets provide an ideal environment in which to study the determinants of oligopolistic firm behaviour and market outcomes as it is determined by the exploitation of unilateral market power. In this paper we analysed the bidding behaviour of a vertical integrated firm bidding in the Italian electricity market. We consider vertically integrated a firm that belongs to an integrated group where some operators are sellers and some other operators are buyers in the wholesale market. In particular we have analysed the behavior of the largest firm (ENEL) taking into account that in many cases she is pivotal, i.e. she is monopolist on her residual demand function. Although theoretical analysis shows that pivotal bidders should supply at the maximum allowed price, we have found that in most of the
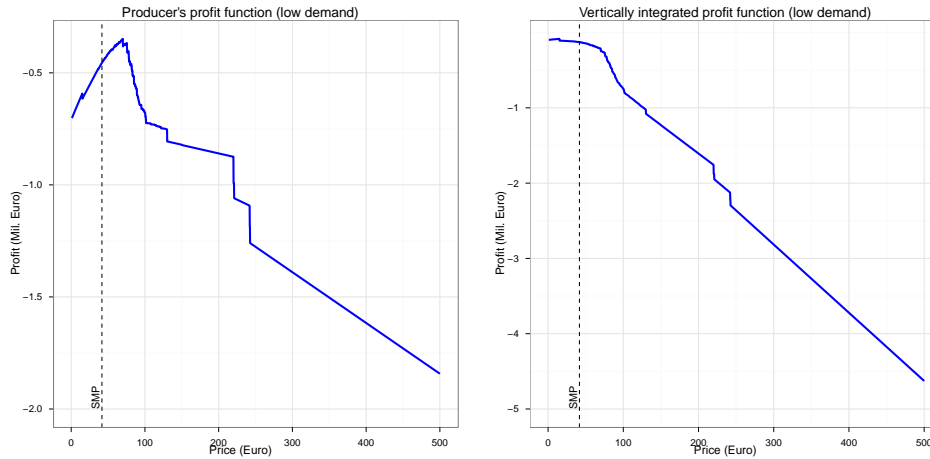
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Figure 6: Profit function of Enel Production and of the Enel Group (vertically integrated). Auction: 17.12.2008:03 (off peak)

cases Enel does not follow this strategy thereby failing to exploit entirely her potential market power. In the paper we have analysed reasons explaining such a behavior and derived numerically a profit function which shows non-concavity with respect to price when the market condition is such that Enel's competitors have exhausted their generation capacity . We have shown that the main explanation for this apparently non-optimal behaviour is given by vertical integration since the behaviour on the market of Enel appears to depend on her net position on the market. We have also explored the way in which the price cap imposed by the Italian market rules may affect bidding behaviour and we have concluded that for a pure producer/seller the actual price cap of 500 is far too high and, under high demand conditions it should be halved. On the contrary, for a vertically integrated pivotal supplier the actual cap seems to be reasonably set.
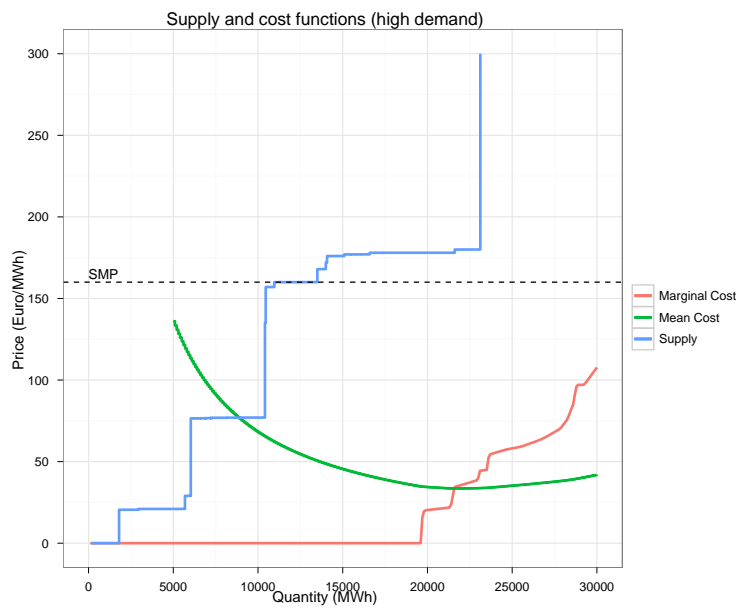
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Figure 7: Marginal and mean cost functions compared with the actual supply curve of Enel. Auction: 02.12.2008:18 (peak)

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