Price-capping in partially monopolistic electricity markets with an application to Italy*

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Abstract

In many electricity markets a supplier can be endowed with a production capacity necessary to satisfy total demand when competitors have exhausted theirs. These *pivotal* suppliers are expected to sell at monopolistic prices on their portions of the market demand.

In this paper we show that the above market conditions may imply that the pivotal profit function may not be concave in price. This means that there can be situations in which a pivotal operator's supply has virtually no price limits. We also show that this monopolistic market power can be significantly reduced by vertical integration and/or some regulatory policy such as VPP. Based on these results, we propose a simple price-capping rule that induces the pivotal operator to compete for quantity instead of taking advantage of its monopolistic condition.

Then, we reconstruct the actual profit function of the Italian pivotal operator (Enel) for the sample period 2007Q1-2010Q4 by means of actual auction data and cost functions used by engineers. We discuss the bidding behaviour of Enel and show how its profit function varies

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over time and in response to pro-competitive measures introduced during our sample period. We criticize the existing price-cap and propose an alternative mechanism.

Keywords: electricity auctions, price cap, optimal bidding.

1 Introduction

Wholesale electricity markets can be modeled as multi-unit auctions where multiple identical objects are bought/sold and demand/supply is not restricted to a single unit. Following the line of research first introduced by Wilson (1979), many scholars have studied the optimal strategies that electricity auctions' players should follow for maximising their profit and the equilibrium resulting from the simultaneous application of these strategies (Brunekreeft, 2001; Parisio and Bosco, 2003; Garcia-Diaz and Marin, 2003; Fabra, 2003; Wolak, 2003; Fabra *et al.*, 2006; Hortaçsu and Puller, 2008; Parisio and Bosco, 2008; Bosco *et al.*, 2011).

Wolak (2003) and Hortaçsu and Puller (2008) approach can be extended in the form proposed by Bosco *et al.* (2011), who generalise it to take into account the presence of vertically integrated operators, that is firms which being both producers and retailers play on both sides of the auction. Indeed, this is a frequent feature of European electricity markets and, in particular, it characterises the Italian market which is the one considered in this paper. As Bosco *et al.* (2011) notice, the model of Wolak (2003) and Hortaçsu and Puller (2008) returns a finite equilibrium price only if there is no *pivotal operator* (i.e., an operator is pivotal if its capacity is necessary to satisfy the market demand whatever the equilibrium price when competitors have already exhausted theirs). Then, if the demand is inelastic to price (at least in the short-run) and barriers to entry into the market are present, the pivotal operator can at least in theory exploit its market power to make equilibrium price arbitrarily high. Many European markets including Italy have pivotal operators at least in peak-time auctions. In this market condition regulatory authorities should take price-capping policies and/or other pro-competition policies into consideration to curbe monopoly power.

In this paper, we study the profit function of a pivotal operator under different market conditions (low and high demand, with and without vertical integration) and show that it is generally non concave and unbounded. This justifies the infinite equilibrium price produced by the model of Wolak (2003), Hortaçsu and Puller (2008) and Bosco *et al.* (2011). We derive a feasible price-capping policy rule, that not only limits the market power of the pivotal operator by setting a bound to the maximum price it can bid, but also leads it to compete for quantity. Then we apply the above price-cap rule to the Italian pivotal operator taking into account auction rounds in which there is a single national market and rounds in which the market is fragmented into zones. Finally other pro-competitive measures as VPP (see Section 3) are also considered in this perspective.

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.We also present a model for the pivotal bidder and show, also with numerical examples, how demand conditions can affect the shape of her profit function for different levels of price. In Section 3 we describe the main characteristics of the Italian electricity market and present our dataset. Then in Section 4 we derive the profit function of the Italian pivotal operator (Enel) under various market conditions and infer the optimal price-cap for the Italian market. We discuss the properties of these empirical profit functions and we compare them with theoretical predictions. Finally we evaluate the possible application of an endogenous price capping rule. Section 5 concludes.

2 Bidding behavior, pivotal operators and regulatory measures to limit market power

Theoretical and applied analyses of wholesale electricity markets are based on two alternative models of bidding behaviour, namely the Wilson's Share Auction model (Wilson, 1979) and the supply function equilibrium (SFE) model (Klemperer and Meyer, 1989). The former is based on the assumption that bidders are uncertain about some private characteristics of rivals (e.g. costs, forward contract positions) and about demand level, whereas in the latter only demand is ex-ante uncertain to bidders while cost levels are known. However, under a set of simplifying assumptions, the first order conditions for an optimal bid/supply function coincide in the two models; whatever the source of uncertainty that characterises the two approaches, it generates random residual demand facing each bidder and therefore it is the distribution of the residual demand that is relevant for bidders who maximise profits defined on their residual demand function. Other simplifying assumptions that are frequently invoked by both lines of research are linear and price-inelastic demand, constant marginal costs and optimal supplies of bidders restricted to be continuously increasing differentiable functions. Another standard assumption typical of the quoted literature it is to treat each hour as an independent auction even if in the reality it is plausible that bidders play a multi-period strategy.

Our analysis is based on a model of share auction already considered in Wolak (2010) and Bosco *et al.* (2011), among others. There are N bidders who 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 (which is the uniform auction price to be paid to all units called into operation) is determined where its supply function $y_i(\cdot)$ intersects its residual demand, namely

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

Total demand has a purely random zero-mean shift component: $\hat{D} = D + \varepsilon$. Under the above assumptions, the probability distribution of the market clearing price, conditional on the supply $y_i(\cdot)$ can be derived as in Bosco *et al.* (2011). Following Bushnell *et al.* (2008) and Bosco *et al.* (2011) we also assume that at least some of the bidders are vertically integrated firms. This means that they may be simultaneously sellers and buyers since they belong to a group having an upstream generator and a downstream retailer. We can assume that the quantity bought for retailing in the electricity auction is fixed (due to long term obligations) to x_i, and that it will be sold at a predetermined price p^r. Under this conditions the optimal bid function satisfies[1]

$$p^e = C_i'\big(y_i^*(p^e)\big) + \frac{y_i^*(p^e) - x_i}{\frac{\partial}{\partial p^e} \sum_{\forall j \neq i}^N y_j(p^e)}. \tag{1}$$

Let $RD_i(p) := \hat{D} - \sum_{\forall j \neq i}^N y_j(p^e)$ be the residual demand facing bidder i. Then, under the assumption of price-inelastic total demand[2], $RD_i'(p) = -\frac{\partial}{\partial p} \sum_{\forall j \neq i}^N y_j(p)$. Equation (1) can be transformed into a Lerner Index where

[1] Under the same set of assumptions and with full knowledge of bidders' costs, SFE models provide the same set of conditions for optimality, as it can be seen in Genc and Reynolds (2011).

[2] See Bosco *et al.* (2011) and in particular the Appendix for the formal derivation of (1) and (2).

the inverse elasticity is calculated given the residual net demand as follows:

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

where $C_i'\big(y_i^*(p^e)\big)$ indicates marginal costs. Equation (2) measures the incentive to use market power when a firm is vertically integrated. Due to vertical integration, the numerator on the rhs of (2) could be positive (negative), when the firm is a net seller (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 very different type of incentives depending on its net position on the market. The same result is obtained by Fabra and de Frutos (2012). 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 pivotal supplier 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 to play a role when demand is near the peak, when the market capacity is limited relative to peak demand and/or when firms capacities are unevenly distributed (Genc and Reynolds, 2011). One interesting case emerges when there is only one firm that is pivotal: this happens when all rival firms' capacity is insufficient to meet the 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 withholding its output at prices below that value[3].

According to this we now assume that i is the pivotal supplier and that the total demand cannot be satisfied even if all competitors of i offer their total

[3]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.

capacity. This implies that there is a price, say $\bar{p}$, above which the residual demand faced by i equals a positive constant, say $\overline{RD}$:

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

As a consequence, the derivative $\frac{\partial}{\partial p} \sum_{j \neq i} y_j(p)$ in equations (1) and (2) equals 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 introducing some regulatory mechanism in electricity markets when a supplier (vertically integrated or not) can be pivotal with positive probability.

Since this event appears to be quite common in electricity markets and only the fear of a regulatory intervention (or some other reason outside the economic analysis) induces firms to bid below infinity, regulators have devised some market rules to prevent the occurrence of the above mentioned perverse incentive. Examples of such rules include some price-capping mechanism or some quantity-reduction mechanisms. The former rule results in an upper limit on price (or sometimes on bid) which is usually set in the electricity spot market. The latter rules place some sort of forward commitment on the pivotal bidder (the bidder who is pivotal with positive probability) in order to reduce $\overline{RD}$. The scope of the present paper is to test the effectiveness of these rules using data of the Italian Power Exchange. To this end, we first establish how forward commitments imposed on the pivotal firm can modify its profit function and then we analyse how a price cap could be efficiently set. Among such commitments Virtual Power Plant (VPP) are very important (see Section 3). VPP are forward commitments that require producers to sell a fraction of their output at a predetermined price, so they work essentially as forward sales. Indeed, apart of bilateral contracts, which are freely negotiated by the firm, contracts signed under the VPP mechanism appear to be of particular interest for our analysis. Regulators worldwide have obliged dominant electricity producers to virtually sell a portion of their power plant production to competitors: starting from 2001, obligations of this kind have been imposed in France, Spain and Italy, as we will describe below. Bilaterals and all kind of forward commitments have been recognized to have a pro-competitive effect in the market (Allaz and Vila , 1993; Wolak, 2000). More generally, forward commitments can be seen as contracts that work in the direction of limiting the incentive to use market power.

In the presence of vertical integration and VPP the profit function of firm i is

$$\pi_i(p) = \begin{cases} (RD_i(p) - x_i - x_{VPP}) \cdot p - C\big(RD_i(p)\big) + p_r \cdot x_i & \\ +p_{VPP} \cdot x_{VPP}, & \text{for } p < \bar{p}, \\ & \\ \big(\overline{RD} - x_i - x_{VPP}\big) \cdot p - C(\overline{RD}) + p_r \cdot x_i & \\ +p_{VPP} \cdot x_{VPP}, & \text{for } p \geq \bar{p}. \end{cases} \tag{3}$$

where x_{VPP} is the quantity corresponding to the VPP committment at the price p_{VPP} and the other symbols have been already associated to variables.

The shape of the profit function for $p < \overline{p}$ depends on how the RD and the cost function behave in that interval; under standard assumptions it will be quasi-concave in prices. On the contrary, for $p > \overline{p}$ the shape of the profit function changes and it becomes 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 as the price increases. In this case there is not a unique global maximum for profits and, when the demand is larger than the other bidders' capacities, we obtain a result similar to that of Genc and Reynolds (2011, Proposition 3): the pivotal bidder's i strategy is to bid at the maximum allowed price while the competitors bid at their profit maximising (lower) price. Notice that the role of x_{VPP} is similar to that of x_i. Therefore in (3), given the sum of forward obligations, a supplier can be pivotal on a smaller portion of the residual demand and as a consequence it has a little incentive to exploit its supply-side market power. This is relevant for the case in which a regulator wants to impose VPP obligations on the firm: if the virtual quantity to be auctioned off is such that the firm is not pivotal on the net quantity, namely when $\overline{RD} < x_i + x_{VPP}$, then the incentive to bid at the maximum price disappears. As a consequence, we can consider the VPP mechanism as working in the same direction as the price cap: the former however is a quantity rule and the second is a price rule. This difference will be seen to be relevant for the actual implementation of the two rules since price caps are usually imposed in centralized exchanges whereas VPP mechanisms works well to limit zonal market power, that is to limit market power of bidders who are pivotal at a zonal level.

In the same setup, the price-cap mechanism could be interpreted as a way to force the pivotal supplier to compete with the other firms by fixing a maximum price p_c that satisfies:

$$\begin{cases} \pi(p_c) < \max_{p \leq \bar{p}} \pi(p), \\ p_c \geq \bar{p}, \end{cases} \tag{4}$$

where $\bar{p}$ is the price above which $RD(p) = \overline{RD}$. The first condition identifies all price levels such that the profit of the pivotal supplier exploiting its monopoly is smaller than the its maximum profit under competition. This capping condition makes competition more convenient than monopoly, since fixing the price at the cap would lower profits. The second condition identifies the price level at which the pivotal supplier is exploiting its partial monopoly. In those cases in which $\overline{RD}$ is very high and the profit function becomes strictly increasing, the interval defined by the rule (4) degenerates into the single point $\overline{p}$ and, thus, the price cap can be reasonably set at $\overline{p}$.

We illustrate the application of the rule (4) through a numerical example inspired by some actual auction results of the pivotal supplier in the Italian power exchange. The plots in Figure 1 are based on a quadratic cost function which well approximates the pivotal supplier's cost function (cf. Bosco *et al.*, 2011). A total competitors' capacity of 40,000 MWh has been supposed for

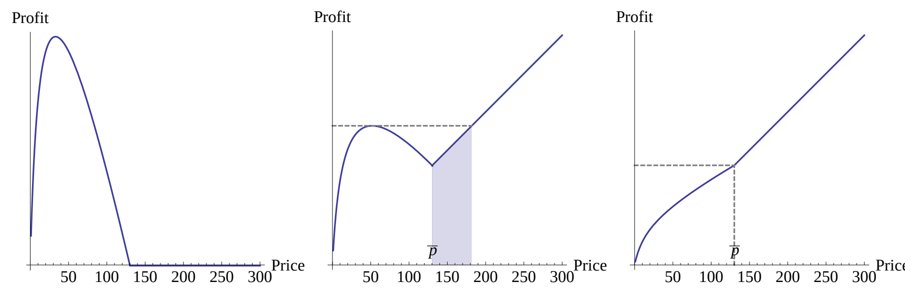

Figure 1: Hypothetic profit curves of the pivotal supplier as functions of price with price-cap intervals.

all three profit functions which refer to three levels of demand: 40,000 MWh (low demand, dominant supplier not necessary), 42,000 MWh (mid demand, monopoly on 2,000 MWh), 50,000 MWh (high demand, monopoly on 10,000 MWh).

By observing Figure 1(a), we see that when the dominant supplier is not pivotal its profit function has the usual (concave with respect to prices) shape and the firm sets the optimal price in competition with rivals. On the contrary, when the dominant supplier is pivotal (Figure 1, panels b and c), the profit is maximised by selling the residual quantity $\overline{RD}$ at a price possibly equal to infinity. These are the conditions under which a price-cap is necessary and the plots illustrate the implementation of rule (4).

In cases similar to the one described in panel (c) it is evident that a price cap alone can be of little use to restore competition and therefore a mix of quantity and price measures should be considered to reach the result. Moreover, a price cap is defined for the wholesale electricity market and it has to hold for all possible market conditions, namely high and low demand, single national market or market split into zones. As such a cap level can be considered as a measure of last resort to prevent particularly high price spikes. On the contrary, VPP obligations can be tailored to specific cases and in particular they can be imposed to firm at zonal level so that they can be effective in restoring competition in the areas where, due to bottlenecks or insufficient capacity, pivotality occurs with high probability. In the next section we describe the functioning of the Italian IPEX alongside the pro-competitive measures adopted so far to foster competition.

3 The Italian power market

In this section we describe the main characteristics of the Italian electricity industry and then we analyze the performance of the Italian wholesale electricity market (IPEX), who started to be fully operational since January 2005. 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 determined by the intersection of supply and demand and the resulting 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 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.

IPEX is considered to be a liquid market with 181 operators in 2010 (91 in 2005)[4] and an average liquidity rate of 65%. Before liberalization and privatization 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 was sold to newcomers with the intention of creating a more leveled playing field. When the market was established, however, the conditions under which firms operated were recognized to be far from competitive. As a consequence, the Italian regulator (AEEG), with the Decision 254/2004, implemented a set of rules to prevent the occurrence of monopolistic conditions in the power market. The regulatory activity was accompanied by an industrial planning that, on the one hand, tried and eased the building of new plants (mainly gas fired CCGT, but also wind and solar plants) and, on the other hand, programmed new interconnecting lines between zones where bottlenecks frequently occurred. Other kinds of regulatory activity will be analysed below.

The monitoring of the evolution of competitive conditions in the power market was realized through the public diffusion of some standard measures of market power, like market shares, Herfindal Index, the index of competition at the

[4]All the data presented in this Section are taken from the last report published by the market operator (GME) in 2011, “Annual report 2011”.

margin (IOM) and an index similar to the RSI, named IOR, that measures the degree of pivotality (both with respect to hours and quantities). In particular the IOM is defined, for each firm and for each zone, as the ratio of volumes on which the operator was the price setter over total volumes sold in the same zone. The dominant operator was marginal from 80% to 90% of the hours during the year 2005, whereas it was marginal only from 10% to 30% of the hours in 2010. The IOR is similar to the RSI used in the California Power Exchange since it is defined as the ratio between residual supply over total supply. As such, IOR is considered an ex-post measure of pivotality. When a pivotal operator exists, the IOR is less than 1 and it approaches 0 as the pivotal quantity which we named $\overline{RD}$ increases. Two versions of the IOR are usually calculated and published by the AEEG: the IORh measures the percentage of hours in which one operator was pivotal and the IORq measures the share of volumes on which one operator was pivotal. In Table 1 we present values of the IOM for the years 2005, 2007 and 2010.

Table 1: Price-setting operator Index: IOM (%)

	2005	2007	2010
Enel	89	77	22
Edison	4	7	14
E.on	1	2	9
Tirreno power	0	1	5
A2A	2	4	8
Others	3	9	42

We notice from Table 1 that the position of Enel as price setter substantially decreased during the period considered whereas the role of competitors as price setters increased substantially. In particular new small operators (Others) have gained importance in the market which is now more open to competition in the price-setting position. On the other hand it must be emphasised that the frequency with which one market participant was necessary appears to be decreasing over the period but still quite high at least in some zones: in C-Nord and C-Sud the frequency is very close to 100%, whereas it is close to 60% in Nord and in Sardinia and close to 70% in Sicily.

Table 2 presents the aggregated IORq measure for the total market and for the six zones. We see that over the whole period the index of market pivotality,

Table 2: Share (%) of sales under non-contestable conditions: IORq (Total and for zones)

	2005	2007	2010
Total	31	21	15
Nord	18	13	9
C-Nord	45	40	30
C-Sud	44	24	33
Sud	60	32	15
Sicily	33	20	15
Sardinia	17	21	7

IORq, decreased both at national level and in all zones. At the same time different zones appear to be characterized by very different competitive conditions: the shares of volumes sold in absence of competition is double in the central part of Italy (C-Nord and C-Sud) with respect to the other zones. However, it must be emphasised that the central zones play a price setter role only in 11% of hours whereas the Nord and Sud zones set the price on the national market in 48% and 16% of the times respectively. The degree of fragmentation into zones of the continental part of Italy is very low and so the lack of competition in central zones is more than compensated by the better competitive conditions in the Nord and Sud zones. Sardinia and Sicily registered a very positive evolution during the five-year period considered due to peculiar policy measures. In Sicily the policy of allowing new generation plants, in particular for base-load, and wind production resulted in an increase in capacity and in a reduction of the degree of market power held by Enel and Edison. The effect on the zonal market was to halve the IORq measure and to change substantially the pre-existing merit order. Another measure that will become effective from 2013 is the empowering of the line interconnecting Sicily with Calabria which should completely include the zone in the continental market. Something very similar happened in Sardinia during the considered five-year period, where the Sapei line produced a sharp improvement in the measures of pivotality: now the percentage of hours with a pivotal operator are 58% against the previous 75%. At the same time E.On, who was the price setter some 25% of the hours, now plays the marginal role 9% of the times. Moreover the new interconnecting line strongly reduced the isolation of Sardinia from the national market: now a zonal configuration emerges 32% of the hours against the previous 54%. Therefore as far as the geographical periphery of the Italian power market is concerned, we can conclude that the increase in interconnecting and productive capacities have been very effective in promoting competition.

Table 3: Percentage of times in which two zones share the same wholesale price. The lower triangular part is for all auctions, the upper triangular part for the high demand auctions of 8pm.

	NORD	CNOR	CSUD	SUD	SARD	SICI
NORD	100	67	59	53	37	5
CNOR	86	100	88	82	60	10
CSUD	79	92	100	93	52	12
SUD	70	82	89	100	49	13
SARD	56	66	62	56	100	8
SICI	25	30	32	33	23	100

Table 3 shows the percentage of times in which two zones share the same wholesale price for all auctions and for the peak auction (cf. next section). As one can see Sicily is the most frequently isolated zone and for this reason it will be used as our zonal empirical case.

Other regulatorary pro-competitive intervention have been introduced before the above mentioned innovations became effective. In particular VPP contracts have been imposed in Italy to some operators in two different cases: the first example is the AEEG Decision n. 19/2005 in which Enel was obliged to virtually sell 3700 MW of its capacity built in the C-Sud zone and 150 MW in Sicily for three years starting from 2006, and the second example is the Decision AEEG n. 115/09 which became effective from 2010 for a five year period in which the two main operators in Sardinia were requested to auction part of their productive capacity (for a total of 25% of the zonal yearly demand) to other operators[5]. In both examples, the selling price is the sum of a fixed part, defined by the AEEG on the basis of variable production costs, and a part resulting from the best bid submitted in the allocation procedure. The operator who sells VPP is obliged to give back to the buyer the difference between the hourly power market price and the fixed VPP price (for quantities effectively exercised[6].). As we noticed in Section 2, VPP sales make part of profits earned by dominant operators independent from the market price and hence for that portion of the quantity they reduce the incentive to exploit the pivotal position.

The increased number of operators in the IPEX and the regulatory interventions described above did not have much influence on the Italian wholesale prices. On the contrary, electricity prices showed an increasing trend until 2008 and a decrease in 2009 and 2010 mainly explained by the industrial downturn due to the worldwide crisis: MGP volumes dropped sharply from 2008 to 2009 (from 337.0 to 313.4 TWh) and a mild recovery was registered in 2010 (318.6 TWh). Table 4 reports annual averages alongside the minimum and maximum values. The comparison between the Italian market and other European markets show that there exists a significant gap between Italian prices and other European prices[7].

[5] In particular, the above mentioned Decision obliged Enel to sell VPP contracts for 225 MW and E.On for 150 MW per year.

[6] It is important to notice that in C-Sud the power market price was more than 5% lower than the strike price for VPP in year 2007

[7] For a long-run analysis of the prices of the main European electricity markets see Bosco

Table 4: Wholesale electricity prices in Italy (Euros)

	2005	2006	2007	2008	2009	2010
Average	58.6	74.8	71.0	87.0	63.8	64.2
Min	10.4	15.1	21.4	21.5	9.1	10.0
Max	170.6	378.5	242.4	212.0	172.2	174.6

4 A price capping rule for Italy

Since April 2004 the Italian day-ahead market (IPEX) worked under a price-cap initially set at 500 Euro/MWh for all bids and then increased to 3000 Euro/MWh in 2008. In the light of the previous theoretical discussion in this section we evaluate the effectiveness of the Italian price-capping mechanism with respect to the behaviour of the pivotal operator.

The first step is the construction of a good approximation of Enel's cost function. During our sample period (2007-2010) Enel operated over 600 power plants: 37 thermoelectric (hydrocarbon-based), 534 hydro, 20 wind-based, 2 photovoltaic and 30 geothermal[8]. Now, since renewable energy sources have negligible variable costs, we concentrate just on the 37 thermal plants.

Thanks to REF (*Ricerche per l'economia e la finanza*[9]), 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 unit. In particular, the cost curve of any production unit j is defined by the quadratic function[10]

$$C_j(Q) = \sum_i \kappa_i \alpha_{ij} (c_{2ij} Q^2 + c_{1ij} Q + c_{0ij}), \tag{5}$$

where 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 share of fuel of type i used

et al. (2010).

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

[9]`www.ref-online.it`

[10]The form of the functions and their coefficient values are based on the technical data of each production unit and computed by plant engineers.

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 is, respectively, Gcal/MW^{2}h, Gcal/MWh and Gcal/h. The index i ranges over the values $\{1, 2\}$. The fuel costs κ_i are time-varying and we use their monthly means in our calculations. $C_j(Q)$ in (5) 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

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

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

In order to build a cost function for a given auction, we merge the ELFO++ data with the database published by the Italian market operator (GME) whose detailed content is reported in Table 5. We use the GME auction data for determining the quantity of electricity Enel is offering through non thermal units, and we compute the aggregate cost function using only those thermal plants whose capacity is actually offered in the auction.

Using the above data 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 of Figure 1. Moreover, as we have no information on the (hourly) fixed costs of Enel, 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.

Table 5: 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

The plots[11] contained in the four Figures 2-5 depict the empirical profit functions (see equation 3) of *Enel Produzione* alone (i.e., the electricity generation company of Enel), and of the vertically integrated Enel Group (i.e., *Enel Produzione* and *Enel Trade*). One peak-load profit function is computed for each day of years 2007-2010; the resulting curves are plotted by quarter. Figure 2 and 3 refer to the whole Italian market, whereas Figure 4 and 5 cover only the Sicilian bids and offers[12]. All the profit functions refer to the peak demand auction of 8pm. According to GME data, around 8pm there is the highest price peak and therefore it is an hour in which it may be assumed that regulatory measures are most needed. Each plot includes, as a vertical band, the range of prices recorded during the quarter, from the minimum to the maximum value.

Starting from *Enel Produzione* considered in the whole Italian market (Figure 2), we notice that the shape of its profit function closely resembles that reproduced in the panel (c) of Figure 1. This is true for the entire 2007 and the first part of 2008. For the rest of the sample we notice a sensible modification of the profit function which becomes similar to the one reported in panel (b) of the same Figure. Each plot of Figure 2 shows the presence of an unbounded

[11] All computations have been carried out using the open-source development environment *R* (R Development Core Team, 2012), with the graphic package *ggplot2* (Wickham, 2009).

[12] Data for Sicily are net of VPP obligations since their introduction.

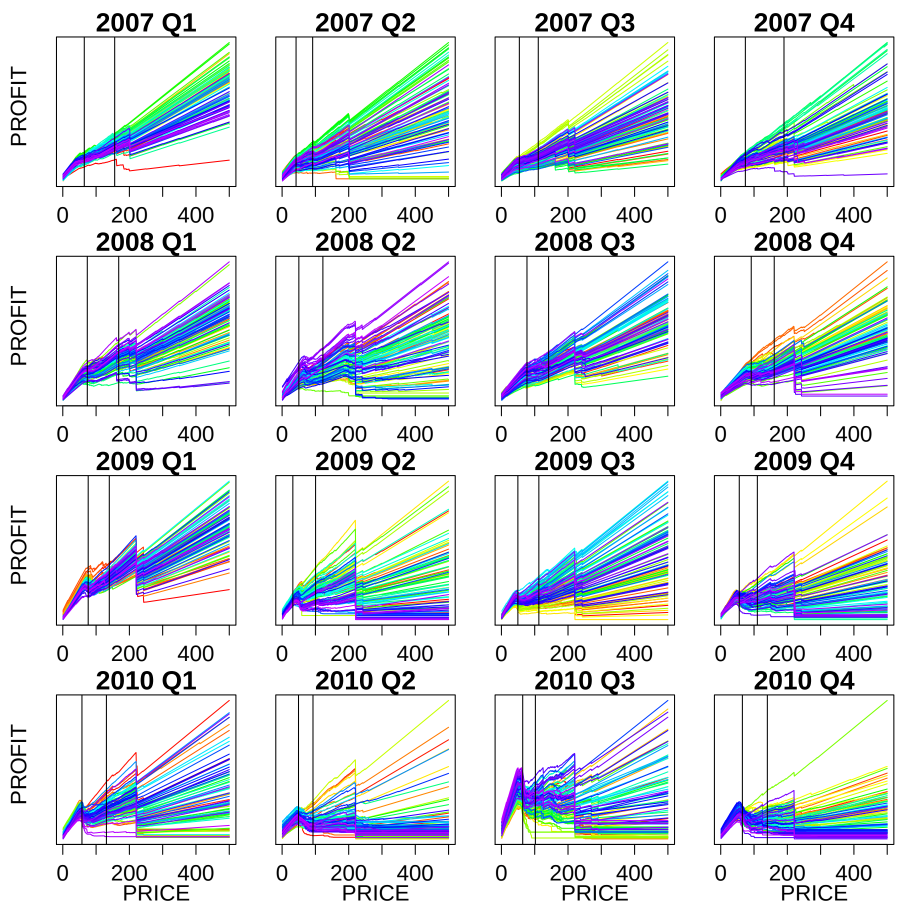

Figure 2: Profit functions of Enel Production (8pm, whole Italy).

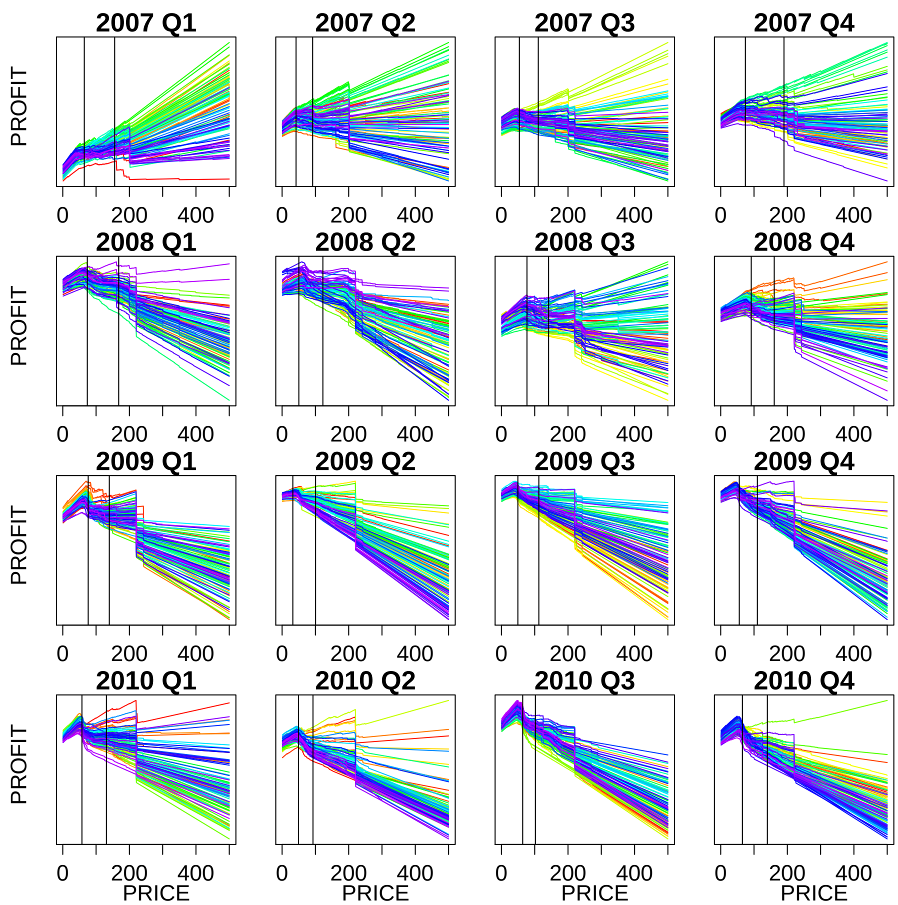

Figure 3: Profit functions of Enel Group (8pm, whole Italy).

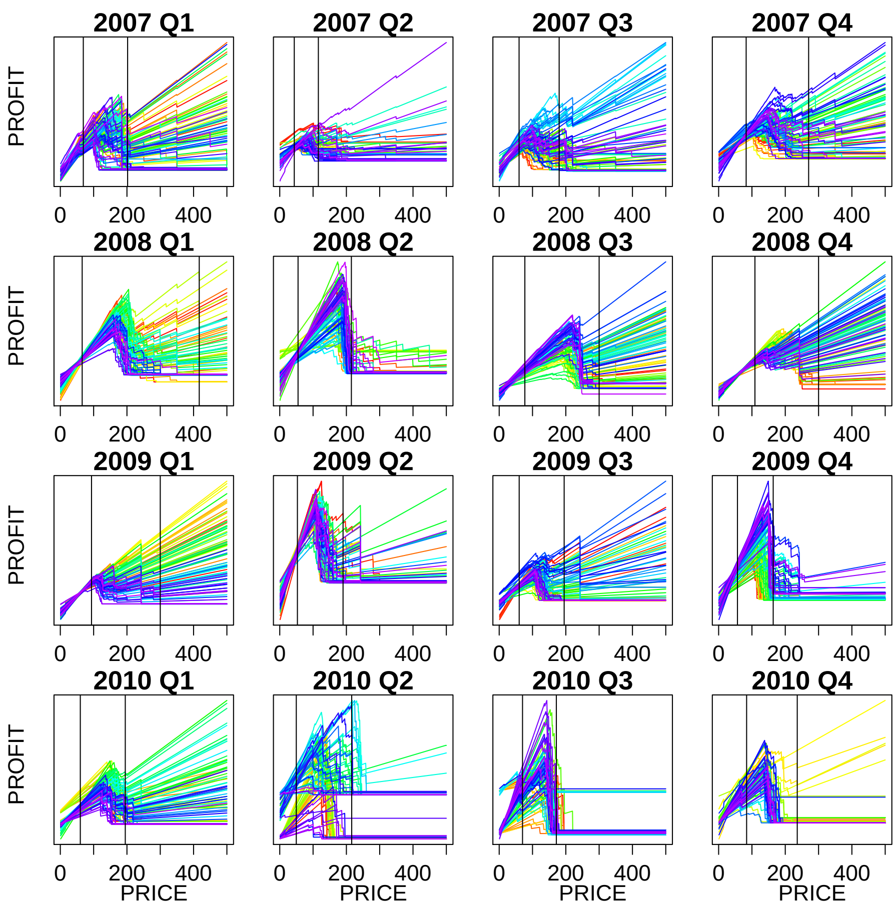

Figure 4: Profit functions of Enel Production (8pm, zone Sicily).

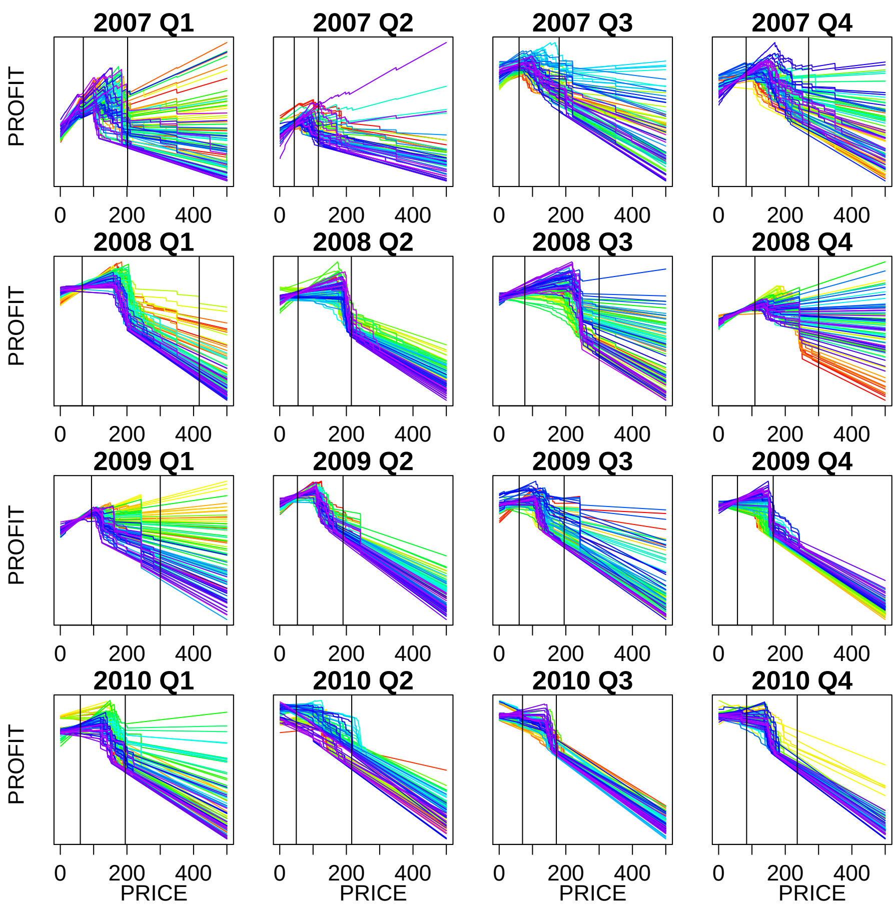

Figure 5: Profit functions of Enel Group (8pm, zone Sicily).

region of profit values following a region in which profit first rises and then declines. There is a small interval of price levels beyond the maximum registered price and corresponding to nearly 220 Euros in which profits drop suddenly as a result of bidding activity of competitors attracted by that price level. When these competitors reach their capacity limits they cannot continue their offer policy whatever the price level. Then *Enel Produzione* becomes pivotal and its profit rises linearly in price.

The change in the profile of the profit function during the sample period is even more pronounced when we consider Enel as a vertically integrated group. In Figure 3 we observe that the empirical profit functions are similar to that of panel (b) of Figure 1 for the year 2007 and the first quarter of 2008 and then it becomes similar to the one in panel (a) from 2009 onwards. Up to a certain price level the behavior of the profit function is similar to the one described for *Enel Produzione* and immediately beyond that level a sudden drop in profit is registered: for higher prices the profit function is increasing from 2007Q1 to 2008Q4 and becomes strongly decreasing in the rest of the sample period, when Enel becomes a net buyer. This accords with the idea that vertical integration reduces market power.

When a single zone (Sicily) is considered, the behavior of the profit functions of *Enel produzione* does not show important differences with respect to the national market case for the first two years of the sample period. The reason why we consider Sicily as an example of a zonal market is that over our sample period this zone is the one more frequently separated from the other Italian zones as shown in Table 3. The other frequently isolated zone is Sardinia where however there are two potentially pivotal operators (Enel and E.On). On the contrary Sicily is a frequently separated zone with only one pivotal supplier. Looking at Figure 4 and in particular from 2009Q4 one can see a sharp modification of the last segment of the profit function which becomes flat. It should be also noticed that the maximum profit from 2009Q2 to 2010Q4 is almost always within the range of the recorded prices. This and the flat portion of the profit beyond some price (above maximum) level should be attributed to the decrease in demand and to the actual exercise of VPP rights that, although theoretically introduced in 2006, started to be implemented in the last part of our sample period[13]. When in Sicily Enel is analysed as an integrated group, it becomes clear that starting from 2009Q2 Enel becomes a net buyer and there is no need of price-capping policies. However, it is still to understand if the likely increase in total electricity demand that will follow the end of the economic crisis will make the Enel Group pivotal again.

As a final general consideration we may say that prices should not be capped at a constant fixed level. On the contrary, a cap should be endogenous to market conditions particularly during peak hours and determined as the price that maximises the profit of the dominant firm when it still plays the competitive game, i.e. when competitors have not entirely exhausted their capacity. In other words, the cap should be the price-bid submitted by the last competitor offering electricity up the demand limit. The price-cap would play a role similar to a second-price payment rule. The usefulness of this mechanism can be evaluated by looking, for instance, at the above plots where a cap consistent with the proposed rule should be set approximately at 221 Euros (the level at which the last competitor of Enel leaves the market[14]). Indeed, if the post-crisis market conditions will bring the profit function of Enel Group back to those of 2007-2008, the existing cap level appears to be far too high, otherwise if Enel remains a net buyer than a positive price-capping is no more necessary.

[13]We thank a anonymous Referee for attracting our attention on this point.

[14]For some reason E.On offers its most expansive production units always at prices between 220 and 221 Euros.

5 Conclusion

In this paper we have shown that the profit function of a firm selling electricity in uniform-price auctions can be non-concave and unbounded from above if its capacity is necessary to satisfy the total demand when competitors have exhausted theirs. Thus, such a *pivotal* firm is supposed to maximise its profit by offering part of its capacity at the highest possible price. We have proposed a simple price-capping rule that induces the pivotal operator to compete for quantity instead of taking advantage of its monopolistic condition on the residual demand. Moreover, we have shown that also vertical integration and other regulatory measures like VPP reduce the optimal bid price of the pivotal operator.

Our results have been evaluated numerically with reference to the Italian market. In particular, we computed Enel's profit function by aggregating the technical cost functions of each thermal production unit and by retrieving its residual demand in peak auctions. As expected, this function is non-concave and unbounded for half of our sample period (2007-2010). On the contrary, when we consider the *Enel Group* (production and retailing activity) the profit of the vertically integrated operator, net of VPP when implemented, increases less rapidly in prices with respect to the non-integrated case. In the last two years considered in our sample (2009-2010), the profit function of the Enel Group is more often decreasing than increasing in price indicating a prevalence of the retailing activity over production (i.e., the Enel Group buys more energy than it produces).

Finally, using these empirical profit functions, we compared the actual fixed-value capping rule with the capping rule discussed in this paper to conclude that the latter gives efficiency advantages.

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