Price coordination in vertically integrated electricity markets. Theory and empirical evidence[*]

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Abstract

We analyse vertical integration in electricity markets by removing the assumption of perfect inter-firms information within a group. Then, we discuss the implication to price decisions of the presence of asymmetric (cost) information between generators and retailers within a simple P-A framework. We interpret the presence of a profit gap with respect to the group's maximum profit as the result of a costly coordination between generator and retailer. Using Italian electricity auction data we show that bid prices posted by generators are significantly moderated by variables incorporating vertical integration into the econometric model. As predicted by our theoretical model, price coordination is only partially fulfilled.

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1 Introduction

Recently restructured electricity markets work as multi-unit auctions (von der Fehr and Harbord, 1993; Wolfram, 1998). In such markets some operators dispose of the production capacity necessary to clear the market when competitors have already exhausted theirs and there is a portion of otherwise not matchable residual demand. These producers are generally called pivotal[1] and they are expected to sell at a monopolistic price on that residual demand and consequently fully exploit their market power. Yet, empirical evidence (Hortaçsu and Puller, 2008; Wolak, 2003; Bosco et al., 2012, 2013) shows that asked prices recorded in wholesale electricity markets are well below the theoretical profit maximizing level, and this finding stimulated scholars to explore different possible reasons explaining this misalignment of theory and empirical outcomes. Among such possible reasons, forward contract obligations (de Frutos and Fabra, 2012), virtual power plant (VPP[2]) auctions (Ausubel and Cramton, 2010) and firms' vertical integration, i.e. selling in the wholesale market at the equilibrium price and simultaneously buying for later

[1]According to Capobianco (2005) "a pivotal operator is an operator whose supply of electricity is necessary to meet the residual local demand on a given market. Residual local demand equates to the hourly demand for electricity on the relevant market, net of imports from abroad less the generating capacity of all other competitors on the same geographic market. Because the supply by the pivotal firm is necessary to meet local demand, such a firm is also considered to have the power to fix the price in the relevant market."

[2]A company that buys VPP capacity obtains the right to deliver power as if it owned a power plant. The capacity is virtual because the "seller" still owns the plant and is responsible for the actual power supply. The purchase of VPP capacity represents a supplement to the purchase of power on the market or from other suppliers. The benefits of VPP capacity include a high degree of flexibility in supply on an hour-to-hour basis. The VPP capacity is normally sold for predetermined periods at an "option price". The option price is set in an auction prior to the period. For each hourly period in which the option is exercised, a pre-determined fixed "energy price" is paid for the actual quantity of power sold. The total payment for the use of the virtual power, thus, consists of an option price and an energy price.

selling to final consumers at regulated prices in a retail market (see Bushnell et al., 2008; Bosco et al., 2012) are the most discussed ones. Vertical integration in electricity markets is also invoked to explain the completely opposite phenomena of overbidding in an auction for the access to an upstream facility (a merchant interconnector) on the part of a downstream integrated firm owned by a legally separated firm belonging to a VIC (Vertically Integrated Company). Burkart (1995) and van Koten (2011, 2012) show that in such an auction the downstream integrated firm will behave more aggressively (by inflating its bid) in order to maximize the joint profit and the auction revenue. Vertical integration can, therefore, produce contrasting results for it leads to price increase in some cases and to price reduction in some other cases. Still, the common element of the above literature on vertical integration is that there is some “bid or price coordination” possibly based on the assumption that information (mainly on cost and demand) is common knowledge to the integrated firms and therefore bidding/pricing coordination is based on a complete and verifiable information set equally shared by those who belong to the group.

In this paper vertical integration is given an encompassing perspective role in the explanation of firms’ supply price coordination in an wholesale electricity market. We remove the assumption of perfect inter-firms information within the group and analyse the implication of asymmetric cost information on the price coordination activity. We explore the implications of a simple Principal-Agent (PA) model of electricity pricing and obtain results that explain supply price moderation as a result of a trade–off between informational rent extraction and group’s profits allocation.

In a sense, in this paper we show another possible use of the so called *counter-speculation strategy*. As recalled by Vickrey (1961) in his *Economics of Control*, A.P. Lerner threw out the interesting suggestion that, where markets are imperfectly competitive, a state agency, through “counterspeculation”, might be able to create the conditions whereby the marginal conditions for efficient resource allocation could be maintained. However, as further noted by Vickrey (1961), Lerner did not made clear just how this counterspeculation was to be carried out, and to many this term denotes just one more of the empty boxes that rattle around in the economist’s cupboard of ideas. We show how the simultaneous activity of selling and buying of a same firm (or different legally separated firms belonging to an integrated group) in the wholesale electricity market can affect supply prices *as if* the retailer firm or branch were counterspeculate against the full exploitation of the market power on the part of the selling firm or branch. We trust that the idea of a counterspeculation activity of market operators (or the opposite phenomenon of *overspeculation*) might extend beyond the case of electricity markets and encompass other cases in which vertical integration is a dominant characteristic of suppliers.

The paper is organized as follows. Section 2 describes the general setting of the model and presents the full information pricing rule for a pivotal generator under vertical integration with a retailer who buys electricity in the wholesale auction market. Section 3 contains the P-A model with the uninformed principal and presents the pricing rule emerging from the incentive scheme designed to induce the generator to disclose its costs and maximize the entire group profit. Section 4 extends the analysis in order to include the specific managerial incentive problem as it can be framed in the vertical integration model. Section 5 presents empirical results for the Italian pivotal operator and for a non-pivotal operator. They show that bid prices of the pivotal supplier is significantly affected by vertical integration according to the predictions derived by the theoretical models. Section 6 concludes and A gives details on some computations.

2 The general setting

We assume that there are two electricity markets: one wholesale and one retail. A group is composed by two firms: a generator G who can sell electricity and faces a residual demand $y(p)$ in the former market at a price p and a retailer R who buys a predetermined quantity $\bar{x}$ of electricity at the equilibrium wholesale price p in that market and sells it at a fixed regulated price $\bar{p}$ in the retail market. An headquarter H coordinates the two firms and instructs G to set an asked wholesale price. Assume there are no fixed costs and let $C_G = cy(p)$, be the cost of G, where $c > 0$ is the constant marginal cost for G, whereas R has no costs apart from $p(c)$. Assume also that H can move funds from R to G in order to induce G to price its quantity in a way that maximizes the entire group's profit. Call this transfer T and assume that it has a unitary "distortion" cost given by $\lambda > 0$.[3]

For simplicity we restrict our interest to a situation in which G is the only *pivotal*

[3]The coefficient λ should be intended as the equivalent to the marginal cost of public funds (MCF) which measures the loss incurred by society in raising additional revenues to finance government spending. As stressed by Dahlby (2008), the MCF has emerged as one of the most important concepts in public economics; it is a key component in evaluations of tax reforms, public expenditure programs, and other public policies.

generator (non-price-setters competitors do not have sufficient capacity and are always despatched in equilibrium and bid at marginal cost). H coordinates G and R and instructs G to bid in order to maximize total profit over the wholesale residual demand.[4] Suppose that all firms bid at marginal costs while the pivotal firm sets the price that maximises its profit over the residual demand. As proved by de Frutos and Fabra (2012, Proposition 3), if this does not constitute an equilibrium, there does not exist any other equilibrium in which such a firm is price-setter[5]. Then, assuming perfect information, the group's profit is $\Pi_H = \Pi_G + \Pi_R - \lambda T$, that is,

$$\Pi_H = [py(p) - cy(p) + T] + [(p - \bar{p})\bar{x} - T] - \lambda T.$$

Π_H is maximized under a participation constraint (PC) given by $T = cy(p) - py(p)$. Substituting for $T > 0$ in the profit function we have

$$\Pi_H = (1 + \lambda)py(p) - (1 + \lambda)cy(p) + (p - \bar{p})\bar{x},$$

which is maximized w.r.t. to p when

$$L \equiv \frac{p - c}{p} = -\frac{1}{\eta_y}\left[1 - \frac{\bar{x}}{(1 + \lambda)y}\right], \tag{1}$$

where η_y is the elasticity of the residual demand. The above is a version of the Boiteux-Ramsey pricing rule corrected for the presence of vertical integration. As

[4]This obviously includes the theoretical possibility that H instructs G of not selling at all at any price.

[5]See also Parisio and Bosco (2003) for such an equilibrium with cost uncertainty.

one can see $\partial L/\partial y > 0$; $\partial p/\partial c > 0$ and $\partial p/\partial \bar{x} < 0$. Overall, the higher the term $\bar{x}/(1+\lambda)y$ the smaller the extent of market power exploitation. Notice, moreover, that the term in square brackets can be positive, negative or zero. The first case occurs when $\bar{x}(1+\lambda) < y$. *Altogether* the group buys less than what it sells in the wholesale market and H instructs G to set the price above marginal cost accordingly, but at a value below the one corresponding to the maximum profit of G only. T compensates G for the (up-to-maximum) profit forgone. Notice that $\bar{x}$ is discounted (or y is inflated) by the shadow cost of internal transfer of resources. The term in square bracket is negative when the opposite condition is realized and G is instructed to set a price lower than marginal cost. When the term in squared brackets is zero the price is equal to marginal cost. Then, given $\bar{p}$ and $\bar{x}$, by setting p, H distributes the overall profit within the group as follows. When

$$0 < \left[1 - \frac{\bar{x}}{(1+\lambda)y}\right] \leq 1$$

it follows that $\Pi_G > 0$ and R makes negative profits net of T. When

$$\left[1 - \frac{\bar{x}}{(1+\lambda)y}\right] = 0$$

it follows that $\Pi_G = 0$ and R makes positive profits net of T.

The above results correspond to de Frutos and Fabra (2012, Lemma 1) for the case of forward contracts. The marginal cost pricing parallels their Proposition 2. Our results encompass also the possibility of an optimal below marginal cost pricing on the part of G as a profit maximizing group strategy. As in Kühn and

Machado (2004, Proposition 1), but without restricting the residual demand to be linear, our results show that prices can be higher or lower than marginal cost if the pivotal firm belongs to a group which is net supplier or net demander in the spot market price. Analogously, van Koten (2011), as mentioned in Section 1 derives the aggressive behaviour of a downstream integrated bidder in a first price auction for the acquisition of an upstream indispensable facility owned by a firm belonging the same VIC. Ours and Van Koten's results are the two sides of the same coin.

3 The asymmetric information case

Assume now that c is observed by G only and H assumes c to be a random variable having a cdf $F(c)$ with $f(c) = F'(c)$ over $[\underline{c}, \bar{c}]$ and $d[F(c)/f(c)]/dc$ is monotonically non-decreasing. To implement a policy of profit maximization of the entire group in this case H must induce G to reveal his cost. Still H maximizes

$$\begin{aligned} \mathrm{E}[\Pi_H] &= \mathrm{E}[\Pi_G] + \mathrm{E}[\Pi_R] - \lambda\,\mathrm{E}[T] \\ &= \int_{\underline{c}}^{\bar{c}} [p(c)y(p(c)) - cy(pc)) + T(c)]f(c)dc \\ &\quad + \int_{\underline{c}}^{\bar{c}} [(\bar{p} - p(c))\bar{x} - T(c)]f(c)dc \\ &\quad - \lambda \int_{\underline{c}}^{\bar{c}} T(c)f(c)dc \end{aligned}$$

but in the presence of unknown costs H has to design an appropriate incentive mechanism to induce cost revelation by G. To derive the incentive constraint (IC) we proceed as follows. H must design a "contract" with G using $p(c)$ and $T(c)$ to induce a cost revelation and a minimum (costly) transfer. Then, he has to incorporate the resulting transfer into the maximization program. It can be shown (see 15) that IC requires

$$\Pi_G^*(c) = \int_c^{\bar{c}} y(p(s)ds + \Pi_G(\bar{c})$$

and the truth-telling transfer

$$T^*(c) = \int_c^{\bar{c}} [y(p(s))]ds - p(c)y(p(c)) + cy(p(c)) + \Pi_G(\bar{c}).$$

Normalizing $\Pi_G(\bar{c})$ to zero and using $T^*(c)$, the expected profit can be written as follows

$$\begin{aligned}
\mathrm{E}[\Pi_H] = &\int_{\underline{c}}^{\bar{c}} \left[\int_c^{\bar{c}} y(p(s))ds \right] f(c)dc + \int_{\underline{c}}^{\bar{c}} \big(\bar{p} - p(c)\big)\bar{x}f(c)dc \\
&- \int_{\underline{c}}^{\bar{c}} \left\{ \left[\int_c^{\bar{c}} y(p(s))ds \right] - p(c)y(p(c)) + cy)p(c)) \right\} f(c)dc \\
&- \lambda \int_{\underline{c}}^{\bar{c}} \left[\int_c^{\bar{c}} y(p(s))ds \right] + (c - p(c))y(p(c))f(c)dc,
\end{aligned}$$

which becomes (see Appendix)

$$\begin{aligned}\mathrm{E}[\Pi_H] = \int_{\underline{c}}^{\bar{c}} \Big\{ &(1+\lambda)[p(c)y(p(c)) - cy(pc))] + (\bar{p} - p(c))\bar{x} \\ &- \lambda y(p(c))\frac{F(c)}{f(c)}\Big\} f(c)dc.\end{aligned} \tag{2}$$

$\mathrm{E}[\Pi_H]$ is maximised with respect to p when

$$p(c) - c = -\frac{1}{y'(p(c))}\left[y(p(c)) - \frac{\bar{x}}{(1+\lambda)}\right] + \frac{\lambda F(c)}{f(c)}. \tag{3}$$

The above price equation reduces to the previous Lerner index of the perfect information case for i) $F(c) = 0$, i.e. when there is no uncertainty; ii) $c = \underline{c}$; iii) $\lambda = 0$, i.e. when there is no efficiency loss induced by the intragroup incentive transfer. Once again, $dp/dc \geq 0$ for $d[F(c)/f(c)]/dc \geq 0$ and $\partial p/\partial(\bar{x}/y) < 0$ independently on the inverse hazard rate as well as $\partial p/\partial \lambda > 0$. We can examine 2 cases.

First case $\bar{x}/(1+\lambda) = y$ (the group sells as much as they buy, in discounted terms). It follows that, using I to indicate this first case,

$$p^I - c = \lambda \frac{F(c)}{f(c)}$$

The price-cost difference is now independent of the elasticity of the residual demand and it is determined by $F(c)$ and positively by λ only. Contrary to the perfect information setting ($F = 0$), in this case $\Pi_G > 0$ since $p^I > c$. It follows that the efficient transfer is

$$T^*(c) = \int_c^{\bar{c}} [y(p(s))ds - \left[\lambda \frac{F(c)}{f(c)}\right] y(p(c))$$

which is the information rent minus the *price-cost difference* obtained for every unit sold. One can verify that $dT(c)/dc < 0$ for $d[F(c)/f(c)]/dc \geq 0$. Notice also that since $\partial p/\partial\lambda > 0$ if the shadow cost of the transfer increases, G is instructed to post a higher asked price in order to reduce, by a lower *T(c)*, the inefficiency cost brought about by the increase of λ.

The second case is when $\bar{x}/(1+\lambda) \neq y$ (the group sells either more or less than they buy, in discounted terms). We obtain (S stands for second case)

$$\left[\left(p^S - c\right) - \left(p^I - c\right)\right] = \begin{cases} y(p(c)) - \frac{\bar{x}}{(1+\lambda)} < 0 & \text{for } \frac{\bar{x}}{(1+\lambda)} > y \\ y(p(c)) - \frac{\bar{x}}{(1+\lambda)} > 0 & \text{for } \frac{\bar{x}}{(1+\lambda)} < y. \end{cases}$$

As one can see the extent of market power exploitation depends on the difference between $y(p(c))$ and $\bar{x}/(1+\lambda)$, i.e. on the net position of the group. With respect to the case in which G sells as much as R buys, the result shows that the maximum value of the difference between the two price-cost margins is obtained with $\bar{x} = 0$ (no vertical integration) and the minimum with $y \to 0$. Since even the latter is a case of no vertical integration we may conclude that monopoly power can be exercised either on the supply or on the demand side of the spot market and that what really matters is the net position of the entire group.[6]

[6]For empirical estimations of the extent of market power when Italian firms are either net sup-

4 The managerial incentive problem

In the previous sections we have considered a transfer paid directly to G. In this section, we analyse the case in which the behaviour of G is determined by a payment to its managers financed out of G's profit. van Koten (2011, 2012) considers a case of vertical integration in which access to a super-profitable market can be reached through an essential facility which is (partially) owned by a company named the upstream firm. The same firm has also the control of a downstream operator which needs access to the scarce resource. The right to use the essential facility and the access price is determined through an auction mechanism in which the downstream operator compete alongside other non-integrated competitive firms. The classical real world example of this setting is an upstream firm that manages an interconnecting line used by downstream electricity generators which compete for scarce access rights necessary to sell in a foreign profitable market. When one of the downstream producers is owned by the upstream firm, then it has a cost advantage with respect to competitors and this fact influences his auction bid and hence the auction revenue for the upstream operator[7]. In particular, the integrated firm is more likely to win the auction and, as a consequence, both the profitability of the competing downstream firms and the efficiency of the allocation mechanism is diminished. In this setting vertical integration reduces welfare and the allocation of

pliers or net buyers, see (Bosco et al., 2012, p.2056).

[7]The incentive problem here is for the principal to offer a compensation scheme to the downstream manager so that he internalises (part of) the positive effect of higher auction revenues on upstream profits. In fact, since the upstream firms earns profits given by the auction revenue, if the downstream firm bids aggressively then auction revenues are enhanced and so the company's profits.

the scarce input through an auction is not sufficient to enhance competition unless other regulatory measure like legal separation of the vertically integrated firm are implemented.

To incorporate the managerial incentive into our problem we proceed as follows. Assume that G is lead by a manager who, without other form of incentives (or incentives based only on the profit he produces), would maximize the reward from his activity. The incentive problem goes through t which is a direct payment made by H to the manager of G, who has utility given by:

$$U = \beta t + \left(1-\beta\right)\Pi_G, \qquad 0<\beta<1 \tag{4}$$

$$\Pi_G = y\left(p\left(c\right)\right)\left[p\left(c\right)-c\right], \tag{5}$$

where, as above, c indicates the constant marginal production cost of the producer, $y\left(.\right)$ is the quantity and $p\left(.\right)$ is the market price.

Using (4) we can write t as:

$$t = \frac{U}{\beta} - \frac{\left(1-\beta\right)}{\beta}\Pi_G. \tag{6}$$

If the manager would truthfully reveal the cost parameter c, then the maximal utility would be $\widehat{U}$ and, by the Envelope Theorem, we can write the incentive constraint as

$$\frac{d\hat{U}}{dc} = -\left(1-\beta\right)y\left(p\left(c\right)\right) \tag{7}$$

Rewriting (5) using (6) we get

$$\Pi_G(c,t) = y\left(p(c)\right)\left[p(c)-c\right] - \frac{U}{\beta} + \frac{\left(1-\beta\right)}{\beta} y\left(p(c)\right)\left[p(c)-c\right] \qquad (8)$$
$$= \frac{1}{\beta}\left\{y\left(p(c)\right)\left[p(c)-c\right]\right\} - \frac{U}{\beta}$$

Π_G is now the profit function net of t. Notice that in this case the money transfer given to the manager of the G firm is paid from his own company so that there are not intragroup compensations.

Next, consider H. The principal maximizes joint profits (weighted with parameter $\alpha > 0$) as follows

$$\max_p \mathrm{E}\left[\Pi_G(c,t) + \alpha \Pi_R(c)\right] = \max_p \int_{\underline{c}}^{\bar{c}} \left[\Pi_G(c) + \alpha\left[\bar{p} - p(c)\right]\bar{x}\right] f(c)\, dc.$$

The Hamiltonian can be written using (8) and the constraint (7) as

$$H = \left\{ y\left(p(c)\right) \frac{1}{\beta}\left[p(c)-c\right] - \frac{U}{\beta} \right\} f(c)$$
$$+ \left\{\alpha\left[\bar{p} - p(c)\right]\bar{x} f(c)\right\} - \mu\left(1-\beta\right) y\left(p(c)\right). \qquad (9)$$

Then for a maximum we need

$$\frac{\partial H}{\partial p} = \frac{1}{\beta} y\left(p(c)\right) + p(c)\, y'\left(p(c)\right) - c\, y'\left(p(c)\right) f(c)$$
$$- \alpha \bar{x} f(c) - \mu\left(1-\beta\right) y'\left(p(c)\right) = 0,$$

$$-\frac{\partial H}{\partial U} = \dot{\mu} = \frac{1}{\beta} f(c).$$

Given that $\mu\left(\underline{c}\right) = 0$, and integrating over $\left[\underline{c}, c\right]$ we get

$$\mu = \frac{1}{\beta} F(c)$$

and, therefore, substituting for μ in $\partial H / \partial p = 0$ we have

$$\frac{1}{\beta} y\left(p(c)\right) f(c) + \frac{1}{\beta} y'\left(p(c)) - c\right) f(c) - \alpha \bar{x} f(c) - \frac{\left(1-\beta\right)}{\beta} F(c)\, y'\left(p(c)\right) = 0$$

Rearranging we obtain

$$p(c) - c = -\frac{y\left(p(c)\right) - \alpha\beta\bar{x}}{y'\left(p(c)\right)} + \left(1-\beta\right)\frac{F(c)}{f(c)}, \tag{10}$$

with $y' < 0$. $\left(y - \alpha\beta\bar{x}\right)$ indicates the net supply of G. The generator does not take into account the whole quantity $\bar{x}$ purchased by R but only a share of it which depends upon how much weight the manager gives to its reward (compared to the profits of the firm he administers) and how much weight H assigns to R. If G and R are given the same weight then $\alpha = 1$. Notice that the role of asymmetric information can be isolated in the (negative) term on the RHS which is independent of the quantity level. In absence of this term and setting $\beta = 0 = \lambda$ we would obtain a Lerner Index that once again corresponds to the perfect information case. Results obtained in the previous equations (1), (3) and (10) can be compared with analogous findings of Kühn and Machado (2004). In a linear supply function equilibrium model with two firms they prove (Proposition 1) that if the retail demand is equal to the power market supply, then there is no incentive to bid above or below marginal production costs. In our models pricing decisions depend not only upon y and $\bar{x}$, but also on the way in which, though the parameters λ, α or β in the objective functions, managers "discount" the value of $\bar{x}$. This introduces in the pricing behaviour a degree of discretion on the part of decision makers.

5 Empirical analysis

Results obtained in previous sections can be subjected to empirical tests. Using data on marginal costs of a set of firms offering and buying electricity in the Italian wholesale electricity market we test the hypothesis that the price-cost difference depends positively on the level of the residual demand facing each generator; positively on the costs of electricity generation; negatively on the quantity demanded by the retailers belonging to the coordinated group of the generator supplying in the spot market. We also infer from the estimations the values of α, β and λ used in the theoretical models.

In this section we first introduce the main characteristics of the Italian electricity industry and then we analyse the performance of the Italian wholesale electricity market (IPEX), which 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) sorts 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 by all accepted buyers. 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.

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. Now IPEX is considered to be a liquid market with a number of 181 operators (91 in 2005)[8] and an average liquidity rate of 65%. When the market was established however, the conditions under which firms operated were recognized to be far from competitive. As a con-

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

sequence, the Italian regulator (AEEG) and the GME implemented a set of rules to prevent the occurrence of monopolistic conditions. The regulatory activity was accompanied by an industrial planning that, on the one hand, tried and ease the building of new plants (mainly gas fired CCGT, but also wind and solar plants) and, on the other hand, designed new interconnecting lines between zones where bottlenecks frequently occurred. 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, an index of competition at the margin (IOM), an index similar to the Residual supply index (RSI), named IOR, that measures the degree of "pivotality" (both with respect to hours and to 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 hours during year 2005 whereas he was marginal only from 10 to 30% of hours in 2010. The IOR can be considered similar to the RSI used in California Power Exchange since it is defined as the ratio between residual supply (in spite of residual capacity) over total supply (in spite of total demand plus export and net of imports in the zone). As such, the IOR is considered an ex-post measure of "pivotality": it is less than 1 when a pivotal operator exists, and it approaches 0 as the pivotal quantity 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. Statistics on IORh and IORq can be found in Bosco et al.

(2012, 2013) showing that the position of Enel as price setter substantially decreased during the last five years whereas the role of competitors as price setters increased substantially. However, 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 decreasing trend in 2009 and 2010 mainly explained by the industrial downturn due to the worldwide crisis. The comparison between the Italian market and other European markets show that there exists a significant gap between Italian prices and other European prices[9].

We conduct the tests using the following hourly data: demand and supply price-quantity bids posted in *MGP* from 2007 to 2010; marginal costs of each generator; equilibrium prices recorded when the Italian market was not segmented in zones (national unique market prices); information about the composition of the largest groups and the "relevance" of each generator within its group. Let us denote with Γ_n the set of production units belonging to the n-th group, with $n = 1, \dots, N$. Then, for any group n and each auction i in which the marginal supply bid was made by

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

a production units belonging to that group, we can estimate the linear model

$$\begin{aligned} \textit{Marginal Supply Price Bid (€)}_i = & \beta_0 + \beta_1 \textit{Marginal Cost (€)}_i \\ & + \beta_2 \textit{Residual Demand (MWh)}_i \\ & + \beta_3 \textit{Group Demand (MWh)}_i \\ & + \beta_4 \textit{Unit Share (\%)}_i + u_i \end{aligned} \tag{11}$$

for all the auctions i in which the marginal generator belongs to Γ_n, where *Residual Demand* is that portion of demand not satisfied by the competitors of group n at the marginal price, *Unit Share* is the quantity offered by the marginal production unit as share of the total quantity offered by group n (the "relevance" of the marginal plant within the group) and u_i is an error term whose properties will be discussed below[10].

Notice that each i represents a single auction but, since there is a limited number of production units that can be marginal, say m, the auctions can be grouped according to the production unit that clears the market. Thus, the error term u_i can be decomposed into two parts: one captures the heterogeneity among different production units and one represents a purely random error[11]:

$$u_i = \mu_i + \nu_i$$

[10]We thank REF (Ricerche di Economia e Finanza, www.ref-online.it) for making available to us their cost data set. For details on the cost data refer to Bosco et al. (2013).

[11]The panel-data literate reader probably expects a notation with two indexes, one for the production-units and one for the time-points, but this is not feasible with our data. Indeed, we have one observation for each auction, which represents a single point in time, but that observation is always related to one price-maker, that is one of the m possible production-units. Thus, the relevant literature is that of *linear mixed models* rather than that on *panel data*.

such that

$$\begin{cases} \mu_i = \mu_j & \text{if in auctions } i \text{ and } j \text{ the same production unit was marginal,} \\ \mu_i \neq \mu_j & \text{otherwise.} \end{cases}$$

If each different μ_i is treated as an idiosyncratic intercept for each production unit, then we have a regression model with *fixed effects*. If, otherwise, the particular structure of the error term u_i is only reflected in its covariance matrix as

$$\mathrm{E}(u_i u_j) = \begin{cases} \sigma_\mu + \sigma_\nu & \text{if } i = j, \\ \sigma_\mu & \text{if } i \neq j, \text{ in auctions } i \text{ and } j \text{ the same unit was marginal,} \\ 0 & \text{if } i \neq j, \text{ in auctions } i \text{ and } j \text{ different units were marginal,} \end{cases}$$

then we have a regression model with *random effects*.

Due to the continuous evolution of the Italian market, we also let the regression intercept vary from year to year. In particular we let year 2007 be the baseline intercept and introduce dummies for the years 2008, 2009 and 2010.

Equation (11) is estimated in different versions. Results reported in this section refers to the major electricity groups operating in Italy, that is, Enel and Edison. According to Bosco et al. (2012) Edison as a group seems to be profit-maximising while Enel Production does not exploit completely its market power. Thus, we expect that Enel, as a group, may act as predicted by the models presented in the previous sections, while Edison should conform to the standard model of profit-maximisation.

The estimates for the generators belonging to Enel are reported in Table 1.

TABLE 1. ABOUT HERE

All the coefficients are significant and have the expected sign. The different scale of the regression coefficients is due to the fact that variables have very different units of measurement (prices range over tens or hundreds, while quantities over tens of thousands). Notice that the higher the demand of the entire Enel group the smaller the bid posted by the marginal generator and this effect is reinforced by the sign and value of the share coefficient.

Individual dummies, not reported, introduce idiosyncratic elements in the interpretation of the bidding behaviour such as technology, location, maintenance, etc. To some extent individual dummies indicate that the efficiency cost of the transfer is not uniform across generators within a group and this reinforces the idea that this cost should be carefully minimized by means of optimal individual supply bids. Hence, altogether estimates indicate that the existence of wholesale market demand of group members affects negatively the level of the asked price on that market, thereby contributing to a non profit maximization behaviour of generators as single entities.

Results obtained for the generators belonging to Edison Group are reported in Table 2. Here the variable *Group Demand* is not significant and this is consistent with previous findings of Bosco et al. (2012), where the behaviour of Edison Group was found to be profit-maximising.

TABLE 2. ABOUT HERE

In order to obtain numerical values for λ, α and β of models (3) and (10), we need "observations" for the variables $y'(p(c))$ and $F(c)/f(c)$. The former is the slope of the residual demand around the equilibrium price and it can be reasonably approximated by a (negative) constant. Since $F(c)$ and $f(c)$ refer to the probability distribution of the marginal costs, we estimated F and f for each year in the range 2007-2010 by kernel smoothing, obtaining $\hat{F}$ and $\hat{f}$ (one for each year). Then, we estimated the ratio as $\widehat{F/f}_i = \hat{F}(c_i)/\hat{f}(c_i)$ where c_i is the marginal cost of the marginal plant in each auction. Formally:

$$\hat{F}(c_i) = \sum_{j \in \Omega_j} \Phi\left(\frac{c_i - c_j}{\gamma}\right)$$

and

$$\hat{f}(c_i) = \frac{1}{\gamma} \sum_{j \in \Omega_j} \phi\left(\frac{c_i - c_j}{\gamma}\right),$$

where Ω_j denotes all the auctions in the sample belonging to the same year of the auction j, while Φ and ϕ are the standard normal distribution and density functions and γ is a bandwidth parameter that we set equal to € 5.

Thus, if we define

$$\Delta p_i = \mathit{Marginal\ Supply\ Price\ Bid}_i - \mathit{Marginal\ Cost}_i$$

the new regression we estimate is

$$\begin{aligned}\Delta p_i(€) = &\beta_0 + \beta_1 \textit{Residual Demand (MWh)}_i \\ &+ \beta_2 \textit{Group Demand (MWh)}_i + \beta_3 \widehat{F/f}_i + u_i,\end{aligned} \tag{12}$$

where, as above, the error term is decomposed as $u_i = \mu_i + \nu_i$. Again, we estimate the regression treating μ_i as a fixed effect or as a random effect with respect to the marginal production unit.

If we relate regression (12) to the model (3), we see that (recall that $y' < 0$)

$$\beta_1 = -\frac{1}{y'(p(c))} > 0, \qquad \beta_2 = \frac{1}{y'(p(c))(1+\lambda)} < 0, \qquad \beta_3 = \lambda > 0,$$

from which $1+(\beta_1/\beta_2) = -\beta_3$, as there are three equations but only two unknowns.

If we relate regression (12) to the model (10), we see that

$$\beta_1 = -\frac{1}{y'(p(c))} > 0, \qquad \beta_2 = \frac{\alpha\beta}{y'(p(c))} < 0, \qquad \beta_3 = (1-\beta) \in [0,1],$$

so that $\beta = 1 - \beta_3$ and $\alpha = -\beta_2/[\beta_1(1-\beta_3)]$.

Notice that for the group's profit-maximising behaviour, the following restrictions on model (12) should hold

$$H_0^H : (\beta_1 = -\beta_2) \wedge (\beta_3 = 0). \tag{13}$$

On the contrary, profit maximisation on the part of the generator alone requires

$$H_0^G : (\beta_2 = 0) \wedge (\beta_3 = 0). \tag{14}$$

These constraints can be easily tested using a Wald type statistic.

Table 3 reports the (fixed and random effect) estimates for the generators belonging to Enel. The signs of all the coefficients are correct even though the coefficient of F/f is not significant. This result does not come unexpected as λ is a very small number and estimates of F/f are affected by a possibly relevant error-in-variable which shrinks the estimated regression coefficient toward zero and inflates its standard error (cf. Hausman, 2001). As the last two lines of Table 3 show, the hypothesis H_0^H of a profit maximising behaviour of the group is strongly rejected. Analogously, the same conclusion can be drawn for the hypothesis that Enel Produzione (the generation company) does not maximise pure generation profits. These two results accord with the predictions of our two theoretical models of partial coordination of supply and demand activity within the Enel group.

TABLE 3. ABOUT HERE

As for the estimates of λ for the generators belonging to Enel in equation (3), we have $\lambda = \beta_3 = 0.0024$ (very probably underestimated), but also $\lambda = -(\beta_1/\beta_2+1) = 6.31$, which is probably an overestimation. If we relate the regression estimates to model (10) we obtain $\alpha = 0.15$ and $\beta = 0.998$, which are both in their respective ranges and show that there exist some sort of group coordination when the generators belonging to Enel submit bids in the wholesale market. There is not a perfect coordination however and this can be explained by the fact that Enel owns a larger market share in the wholesale market than in the retail market (27.7% against 17.9% in 2010). Hence the relatively larger market power in the upstream market is exploited setting prices higher than marginal costs, but lower than those corresponding to the profit-maximising levels.[12]

6 Conclusion

This paper addressed the question of how a vertically integrated power producer can coordinate its supply activity in a wholesale market with a downstream retailer. Vertical integration is recognized to reduce market power of dominant firms when they act as a part of a group. We introduce two simple Principal-Agent models to describe price coordination of firms in the presence of asymmetric information about generation costs. In the first version of the model the holding company is able to coordinate the activity of the generation firm through an incentive mechanism which requires an intra-group (costly) transfer of funds. In the second version of the model intergroup money transfer is not contemplated and so the incentive scheme works through a reward guaranteed to (the manager of) the upstream seller. Our general conclusion is that vertical integration reduces the incentives to exploit market power but in both models we find that the upstream firm only partially coordinates with the downstream retailer since only a portion of the retail quantity demanded is

[12]Similar estimates and tests have been also run for Edison, which sometimes is marginal but never pivotal. As expected, estimates indicate (consistently with the results reported in Table 2) that Edison seems to follow a group profit-maximising behaviour. Results are available upon request.

subtracted from the residual demand served by the power producer. In both models group's profit maximization generates prices which are *ceteris paribus* higher than the ones resulting in a model of perfect coordination such as the one presented by Kühn and Machado (2004).

Empirical tests conducted using Italian data not only confirm that supply bids are negatively affected by group's demand and cost levels, but also show that the hypothesis of partial coordination between generators and retailers of the same group is consistent with the data. This finding emerges when data refer to the case in which the generator acts as a monopolist on (a portion of) the residual demand.

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A Computations

IC derivation is standard and follows Baron and Myerson (1982) paper. G can report marginal cost truthfully (c) or not ($\hat{c}$) to H. This implies that

$$\text{for } \hat{c} = c : \Pi_G(c,c) = p(c)y(p(c)) + T(c) - cy(p(c))$$
$$\text{for } \hat{c} \neq c : \Pi_G(\hat{c},c) = p(\hat{c})y(p(\hat{c})) + T(\hat{c}) - cy(p(\hat{c}))$$

and we need for a truth telling mechanism to be implementable that

$$\Pi_G(c,c) \geq \Pi_G(\hat{c},c), \qquad \forall c \in [\underline{c},\bar{c}]$$

Then, from the Envelopment Theorem we have

$$\frac{d}{dc}\Pi_G^* = \frac{d}{dc}\Pi_G^*(\hat{c}(c),c)\bigg|_{\hat{c}=c} = -y(p(c))$$

from which the global condition is obtained by integration from c to $\bar{c}$, yielding

$$\Pi_G^*(c) = \int_c^{\bar{c}} y(p(s)ds + \Pi_G(\bar{c}) \qquad (15)$$

which corresponds to the one used in the text.

Derivation of equation (1). With simple manipulation the expression for $E[\Pi_H]$

written in the text rewrites

$$\begin{aligned}\mathrm{E}[\Pi_H] = &\int_{\underline{c}}^{\bar{c}} (1+\lambda)\left[\left(p(c)-c\right) y(pc))\right] f(c)dc + \int_{\underline{c}}^{\bar{c}} \left[\bar{p}-p(c)\right]\bar{x} f(c)dc \\ &-\lambda \int_{\underline{c}}^{\bar{c}} \left[\int_{c}^{\bar{c}} y(p(s))ds\right] f(c)dc\end{aligned}$$

Integrating by parts the double integral gives

$$\int_{\underline{c}}^{\bar{c}} \frac{F(c)}{f(c)} y(p(c)) f(c)dc$$

and by substitution we get equation (2), i.e. the expression for the expected profit used in the text.

TABLES

Table 1: Estimates of model (11) for Enel.

	Fixed Effects			Random Effects		
	Estimate	Std. Error	p-value	Estimate	Std. Error	p-value
Intercept				12.9700	2.3000	0.0000
Year 2008	7.2990	1.1440	0.0000	9.8970	1.0850	0.0000
Year 2009	21.3900	1.0560	0.0000	21.9000	1.0550	0.0000
Year 2010	32.4900	1.2420	0.0000	34.3900	1.2200	0.0000
Marginal Cost	0.8281	0.0448	0.0000	0.6819	0.0396	0.0000
Residual Demand	0.0057	0.0001	0.0000	0.0057	0.0001	0.0000
Group Demand	-0.0007	0.0002	0.0055	-0.0006	0.0002	0.0131
Unit Share (%)	-6.1910	0.5271	0.0000	-5.5750	0.5134	0.0000

Number of observations 2777, number of production units 61.
Fixed Effects: $R^2 = 0.67$, $F_{67,2709} = 80.44$ (p-value= 0.0000).
Random Effects: $\text{Var}(\mu_i) = 129.12$, $\text{Var}(\nu_i) = 254.04$.

Table 2: Estimates of model (11) for Edison.

	Fixed Effects			Random Effects		
	Estimate	Std. Error	p-value	Estimate	Std. Error	p-value
Intercept				46.4100	4.6550	0.0000
Year 2008	1.0880	2.2330	0.6263	1.3650	2.2190	0.5386
Year 2009	16.5500	2.1370	0.0000	16.0600	2.1290	0.0000
Year 2010	5.1400	2.5590	0.0448	4.9360	2.5590	0.0539
Marginal Cost	1.5690	0.0854	0.0000	1.5410	0.0839	0.0000
Residual Demand	0.0025	0.0002	0.0000	0.0025	0.0002	0.0000
Group Demand	0.0006	0.0008	0.4494	0.0008	0.0008	0.3251
Unit Share (%)	-3.2240	0.2505	0.0000	-3.1770	0.2499	0.0000

Number of observations 1055, number of production units 11.
Fixed Effects: $R^2 = 0.69$, $F_{17,1037} = 137.4$ (p-value= 0.0000).
Random Effects: Var(μ_i) = 53.38, Var(ν_i) = 146.89.

Table 3: Estimates of model (12) for Enel.

	Fixed Effects			Random Effects		
	Estimate	Std.Error	p-value	Estimate	Std.Error	p-value
Intercept				-2.1975	2.9684	0.4593
Year 2008	2.5880	0.9219	0.0050	2.7100	0.9203	0.0033
Year 2009	19.6600	1.1210	0.0000	19.9451	1.1186	0.0000
Year 2010	29.5900	1.2290	0.0000	29.9090	1.2265	0.0000
Residual demand (β_1)	0.0055	0.0001	0.0000	0.0055	0.0001	0.0000
Own demand (β_2)	-0.0008	0.0002	0.0024	-0.0008	0.0002	0.0015
F/f (β_3)	0.0024	0.0025	0.3442	0.0015	0.0025	0.5552
$H_0^H : \beta_1 = -\beta_2, \beta_3 = 0$	352.44		0.0000	342.85		0.0000
$H_0^G : \beta_2 = 0, \beta_3 = 0$	10.07		0.0065	10.38		0.0056

Number of observations 2077, number of production units 61.
Fixed Effects: $R^2 = 0.63$, $F_{66,2710} = 69.14$ (p-value= 0.0000).
Random Effects: Var(μ_i) = 411.07, Var(ν_i) = 277.46.
Tests for linear restrictions are chi-square with 2 d.f.