Price Coordination in Vertically Integrated Electricity Markets: Theory and Empirical Evidence

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ABSTRACT

We analyse vertical integration between generators and retailers in electricity markets and we discuss the implications for price decisions of the presence of asymmetric (cost) information in a simple P-A framework. We analyze a situation in which generators post supply bids taking into account the profit of the entire vertically integrated group they belong to. We then discuss the way in which the degree of vertical integration affects this bidding strategy. Using Italian electricity auction data we show how bid prices posted by a pivotal producer are significantly influenced by variables incorporating vertical integration into the econometric model.

Keywords: Regulation, vertical integration, electricity markets, strategic delegation

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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 so, fully exploit their market power. Yet, empirical evidence (Hortaçsu and Puller, 2008; Wolak, 2003; Bosco et al., 2010, 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; Ausubel and Cramton, 2010a),

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 considered to have the power to fix the price in the relevant market.

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virtual power plant (VPP)[2] auctions (Ausubel and Cramton, 2010b) and firms' vertical integration[3] are the most discussed ones.

Papers analyzing the behavior of vertically integrated firms in electricity markets (Bushnell et al., 2008) assume that their bids maximize the profit of the entire group. There is no evidence, however, on how independent firms belonging to the same group can coordinate their actions to achieve this goal. In this paper we look inside the black box of a vertically integrated firm and try to model—and then estimate—how the relationship between the producer and a seller belonging to the integrated group and operating in the same wholesale market affects the bidding behavior of the former. We assume that an electricity generator and a retailer belong to the same parent company and that they simultaneously sell and buy electricity in the wholesale auction. The retailer will resell the energy to final consumers who pay regulated prices. The parent company coordinates all activities and is interested in the group's net profit. We model this coordination by a simple Principal-Agent (P-A) model and explore the implications for electricity pricing and bidding conduct in a wholesale market. This coordination can be costly in terms of intra-group efficient allocation of resources and we show how generators' bidding behavior is affected by this cost. We also estimate empirically the magnitude of this effect for a vertically integrated firm which is a dominant player in the Italian wholesale market.

The paper is organized as follows. Section 2 introduces the theoretical analysis and presents a bidding model of a vertically integrated supplier in a wholesale electricity market. Section 3 contains empirical results obtained for two vertically integrated Italian firms. We show that bid prices of suppliers are, at least for a sub-period of the sample, significantly affected by vertical integration according to the predictions derived by the theoretical model. Section 4 concludes.

2. THE MANAGERIAL INCENTIVE PROBLEM

We model electricity transactions as they are organized in real-world markets. Electricity is exchanged in a wholesale market which works as a two-side auction: generators submit sale offers as price-quantity pairs while retailers bid to buy bulk electricity. The market operator orders bids (offers) in a non-increasing (non-decreasing) way and calculates the market equilibrium at the intersection of demand and supply. The clearing price, named SMP (System Marginal Price), is paid to all dispatched producers. Since retailers sell to their customers the electricity they have purchased wholesale, their profits are determined by the difference between the selling price (which is often regulated) and the SMP.

Under textbook market conditions demand and supply would act independently and coordinate their decisions through the market. The electricity market however, is still characterized by the presence of vertically integrated firms. In fact there are producers and retailers which are

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.

3. Selling in the wholesale market at the equilibrium price and simultaneously buying for later selling to final consumers at regulated prices in a retail market (Bushnell et al., 2008; Bosco et al., 2012).

legally separated but nonetheless they are under the control of the same parent company which faces the problem of profit allocation inside the group. This happens for example when one side of the market, typically the supply, enjoys a higher degree of market power with respect to the other side. Given the SMP rule, a high equilibrium price raises the profits of the generator but induces tight profit conditions for the retailer. For that reason we expect that the holding firm may wish to follow an "implicit" profit redistribution activity inside the group. To this end the parent tries to influence the bidding behavior of the branch endowed with the higher degree of market power to the advantage of the other branch. How this can be done depends upon the structure of the incentives existing inside the group. To explore this issue, in this Section we introduce a Principal-Agent model designed to describe the way in which the holding firm sets the right incentive for one branch to maximize group profits. The model is also used to obtain predictions on the bidding behavior to be subjected to empirical analysis.

We assume that a group is composed by two operational firms, a generator G and a retailer R, and by a parent firm H which coordinates their activities. G and R are legally independent and compete on the supply and demand side respectively of a wholesale electricity market. G is assumed to maximize profits given its residual demand, $y(p)$, defined as total market demand minus the other firms' supply when the price that it sets in the market equals p.[4] R buys a predetermined quantity $\bar{x}$ of electricity at the price p and it then sells $\bar{x}$ at a fixed regulated price $\bar{p}$ in the retail market.[5] H coordinates the two firms in order to maximize the entire group profits. H's goal may not be in line with the goal of G since the latter may wish to maximize its own profits. In the model we allow for the possibility that H assigns a different weight to the (profit of) the two branches in its objective function.[6] The problem is therefore to introduce an incentive for G to set an asked wholesale price which will not destroy the retailer's profit opportunities. This situation is particularly compelling when supply conditions are such that the generator is a monopolist on the residual demand (pivotal generator) so that it could fix a price up to the market cap. For this reason we restrict our interest to a situation in which G is the only firm that is *pivotal* while competitors do not have sufficient capacity to be price-setter.[7]

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, whereas R has no costs apart from p, i.e. the wholesale price. The model is characterized by asymmetric information between the holding firm H and the generator G. We model asymmetric information assuming that the marginal cost of production c is observed by G only and H assumes c to be a random variable having a cdf $F(c)$. We assume that $f(c) = F'(c)$ over $[\underline{c}, \bar{c}]$ and that $d[F(c)/f(c)]/dc$ is monotonically non-decreasing. The asymmetric information assumption can be justified on the grounds that the generator is a legally separated and an economi-

4. A non-integrated profit maximizing producer has an optimal bidding strategy where the price-cost margin is inversely related to the price elasticity of its residual demand function.

5. Domestic consumers in Italian retail market showed a very low switch rate since the full liberalization of July 2007. The majority of consumers are still in the regulated portion of the market. For that reason retail quantity is price insensitive whereas tariffs are under the control of the Italian regulatory authority AEEG

6. This may be due to a different shareholding inside the group or to a different attitude towards consumers justified by a partial firm ownership by the public sector.

7. In this case, as proved by de Frutos and Fabra (2012, Proposition 3), there is no loss of generality (as far as equilibrium outcomes are concerned) in restricting attention to equilibria in which the non-price-setters bid at marginal costs and the price-setter maximizes its profits over the residual demand. See also Parisio and Bosco (2003) for such an equilibrium with cost uncertainty.

cally independent entity with respect to the holding firm. In this framework, a full ex-ante knowledge of cost conditions cannot be guaranteed and (the manager of) generator G has the incentive to conceal this information to the benefit of his own firm.[8] To implement a policy of profit maximization of the entire group H must therefore induce G to reveal his cost.

We incorporate the managerial incentive into our problem as follows.[9] Assume that G is lead by a manager who, without other forms of incentive, would maximize the profit of his firm. This is defined by:

$$\Pi_G = y(p(c))[p(c)-c], \tag{1}$$

where, as above, c indicates the constant marginal production cost of the producer, $y(.)$ is the quantity and $p(.)$ is the market price. The incentive for G to behave according to H's policy is obtained through a payment made to the manager and financed from G's profits. We define t as a direct payment made by H to the manager of G, who has utility given by:

$$U = \beta t + (1-\beta)\Pi_G, \qquad 0<\beta<1 \tag{2}$$

In (2) the manager weights, with parameter β, his personal reward and the company's profits. From (2) we can write t as a function of U:

$$t = \frac{U}{\beta} - \frac{(1-\beta)}{\beta}\Pi_G. \tag{3}$$

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

$$\frac{d\hat{U}}{dc}\Big|_{\hat{c}=c} = -(1-\beta)y(p(c)) \tag{4}$$

Rewriting the generator's profits (1) using (3), we get

$$\begin{aligned}\Pi_G(c) &= y(p(c))[p(c)-c] - \frac{U}{\beta} + \frac{(1-\beta)}{\beta}y(p(c))[p(c)-c] \\ &= \frac{1}{\beta}\{y(p(c))[p(c)-c]\} - \frac{U}{\beta}\end{aligned} \tag{5}$$

where Π_G now has been rewritten net of t. Notice that the money transfer t given to the manager of G is paid out from G's own profits so that there are not intragroup compensations.

Next, consider H. The principal maximizes the group profits as follows:

8. A firm that earns high profits may gain advantages in the industry where it operates but it can also become more powerful inside the group. For these reasons we can believe that it is not obvious that the generator maximizes the group profits without an appropriate incentive to do so.

9. See also van Koten (2011).

$$\max_p E[\Pi_G(c,t)+\alpha\Pi_R(c)]=\max_p \int_{\underline{c}}^{\bar{c}}[\Pi_G(c)+\alpha[\bar{p}-p(c)]\bar{x}]f(c)dc. \tag{6}$$

The parameter $\alpha > 0$ allows for the possibility that H may give a different weight to the profits of each firm belonging to the group.[10] The Hamiltonian can be written using (5) and the constraint (4) as:

$$H=\left\{y(p(c))\frac{1}{\beta}[p(c)-c]-\frac{U}{\beta}\right\}f(c)+\{\alpha[\bar{p}-p(c)]\bar{x}f(c)\}-\mu(1-\beta)y(p(c)). \tag{7}$$

Then for a maximum we need

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

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

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

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

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

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

Rearranging we obtain

$$p(c)-c=-\frac{y(p(c))-\alpha\beta\bar{x}}{y'(p(c))}+(1-\beta)\frac{F(c)}{f(c)}, \tag{8}$$

with $y'<0$. For an easier comparability with results of the previous literature we can rewrite (8) in terms of elasticity as follows:[11]

$$\frac{p(c)-c-(1-\beta)\frac{F(c)}{f(c)}}{p}=-\frac{1}{\eta_y}\left(1-\frac{\alpha\beta\bar{x}}{y}\right) \tag{9}$$

where $(c+(1-\beta)F(c)/f(c))$ indicates the virtual marginal cost of the integrated firm arising from the incentive compatibility constraint. Notice that in the case of perfect information and absent any

10. Alternatively, one may assume that H owns only a share α of R.
11. We thank an anonymous Referee for having suggested this formulation.

form of coordination between branches, the price-cost margin in (9) is inversely related to the elasticity of residual demand $1/\eta_y$. In (9) the term $(1-\alpha\beta\bar{x}/y)$, whose value ranges between 0 and 1, is a scaling factor of the inverse elasticity. When the scaling factor equals one ($\beta=0$), we obtain the optimal supply of a non-integrated producer. On the contrary, in a perfectly integrated group, where generator G and retailer R are given the same weight, β and α would be both equal to one and $(y(p(c))-\bar{x})$ would be the net demand of the group in the wholesale market. In this case G would bid according to a strategy of profit maximization at the group level even if it could increase its own profits at the expense of R. Under imperfect coordination, $0<\beta<1$ and the generator discounts from his total supply only a portion of the downstream demand which depends upon how much he weights his own reward against the profits of the firm and how much weight H assigns to the profit of R.

To summarize the above results we may stress that the bidding strategy is affected by the parameters characterizing the incentive mechanism implemented within the integrated group. The highest bid is obtained when firm G follows an individual profit maximizing strategy and so there is no coordination inside the group. The lowest bid is expected as a result of the above described incentive mechanism when full coordination is achieved. Empirical analysis might help to understand how this mechanism works in practice and what its impact on the price policy of G can be.

Using data of vertically integrated firms selling and buying electricity in the Italian wholesale electricity market (IPEX), in the next Section 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 and negatively on the quantity demanded by the retailer belonging to the same group of the generator. We are also able to infer from the estimated parameters the values of α and β in (9).

3. EMPIRICAL ANALYSIS

In this section we first describe the main characteristics of the Italian power exchange (IPEX) which generated the data used for our estimates and then we present the structure of the main groups considered in the analysis.[12]

The IPEX is a wholesale market in which delivery programs are scheduled in a sequence of centralized auction mechanisms. The day-ahead market (MGP) is a two-sided auction in which 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 decreasing 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 dispatched suppliers.

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 levelled playing field. Now IPEX is considered to be a liquid market with 181 operators (91 in 2005) and an average liquidity rate of 65%.[13]

12. All the data presented in this Section are taken from the report published by the market operator (Gestore del mercato elettrico, GME) in 2011, “Annual report 2011”.

13. The liquidity rate is defined as the ratio of volumes traded in the MGP to total volumes traded in Italy (including bilaterals).

Table 1: Data for Enel and Edison when Italy is One Market and They Own the Marginal Production Unit

	Year	P	Q	MC	RD	QD	QS	F/f
Enel	2007	43.6	179.6	38.1	2,084.5	5,043.2	18,811.7	56.0
	2008	67.9	244.1	58.1	2,723.8	6,743.3	20,081.2	82.4
	2009	50.0	162.3	30.4	−263.7	6,033.5	20,780.4	78.1
	2010	54.4	131.7	33.2	−2,819.0	4,220.3	20,438.7	46.4
Edison	2007	54.7	43.8	31.2	−15,217.1	605.4	2,347.2	17.5
	2008	89.1	66.3	47.3	−12,929.3	1,665.5	3,660.5	13.1
	2009	63.3	77.3	30.5	−17,496.9	1,965.5	2,913.2	19.3
	2010	63.6	80.7	41.5	−19,747.3	2,542.0	3,145.2	25.4

P: average price offered by marginal unit (Euro).
Q: average quantity offered by the marginal unit (MWh).
MC: average marginal cost (Euro).
RD: average residual demand (MWh).
QD: average quantity demanded by retail firm (MWh).
QS: average quantity supplied by producing firm (MWh).
Ff: kernel estimates of $F(c)/f(c)$.

Notwithstanding some relevant pro-competitive regulatory provisions, which aimed at reducing the monopoly power of the former monopolist, during the sample period Enel registered a market share over 31% while Edison, which is the second-largest operator, registered a share of 11%. Data on market concentration published yearly by the Italian Regulatory Authority (AEEG), namely, the Herfindal index, the Index of Marginal Operator (IOM) and the Index of Residual Operator (IOR) confirm the leading position of Enel in the Italian market. IOM is defined as the ratio of volumes on which each price-setting operator was marginal over total volumes sold. The IOM halved for Enel from 50.6% to 25.1% in the sample period, whereas for Edison it decreased from 12.1% to 10.6%. The IOR measures the degree of pivotality of a price-setting seller as the ratio of total volumes offered by competitors over total volumes sold. Two versions of the IOR index are published: IORh measures the percentage of hours in which a producer was pivotal while IORq measures the share of quantities for which the producer was necessary. They both range from 0 to 1. The IORh measured for ENEL decreased from 76,7% in 2007 to 59,8% in 2010, whereas for Edison the IORh was almost zero during the whole sample period. For year 2010 and taking into account all the auctions/hours ENEL Produzione was the price-setting firm with a frequency of 22.0% while the same measure was 14.4% for Edison.

The Italian market splits into up to six zones when interconnection flow limits are reached and this implies that different prices prevail in each separated zone. To conduct a nationwide analysis, we then use data only from those auctions in which Italy was one single market, which represent in our sample period some 20% of the total number of hours and 17% of the total quantity exchanged. Table 1 reports a summary of the data used in our empirical analysis in every year of the sample. As for the demand side, we notice that both firms, Enel and Edison, have a retail branch which buys electricity in the MGP. The ratio between quantity demanded and supplied ranges from 21% to 33% for Enel and from 26% to 81% for Edison. On average Edison seems to be more vertically integrated than Enel whereas the latter enjoys a higher degree of pivotality in the market. In fact, in the first two years of the sample, Enel always faces a positive residual demand and this indicates that quantities supplied by all other producers are not enough to satisfy the demand. Enel's production is therefore essential to the market equilibrium in 2007 and 2008 but loses this role in

2009 and 2010. Residual demand for Edison has a negative average value for all the years in the sample which means that Edison's supply is (on average) never necessary to match the total demand. Edison is rarely a price setter in these market configurations and in our sample we observe less than 44 cases per year in which a thermal unit belonging to Edison group is pivotal.

Results reported in Table 1 permit the evaluation of the Lerner index for the two firms. Enel experienced an average percentage mark-up on marginal costs of 12.6% in 2007 which reached a value equal almost to 39% in 2010 thereby signaling a sharp increase in the exploitation of its market power. This should be also evaluated in the light of the material reduction in the quantity sold. On the contrary, the average Lerner index of Edison is high during the entire sample period but shows a decreasing pattern: from 43% in 2007 to 35% in 2010 when the quantity sold almost doubled with respect to the 2007 value.

A deeper analysis of the dataset shows a large variability of the measure of vertical integration among hours due to the well known seasonality of electricity data. In fact, there are hours in which firms are net demander in the market (a fact that suggests an optimal strategy of bidding below marginal costs) even if in the majority of auctions they are net suppliers.

Our estimates are conducted using hourly MGP data recorded when the Italian market was not segmented in zones (national unique market prices) including price-quantity bids (supply and demand) and equilibrium prices. The cost function of every thermal unit in the Italian zones has been obtained using technical data and monthly fuel costs provided by REF-E.[14] Notice that our cost functions are only approximations to the real cost functions since they are based on public information about the type of each thermal production unit and because they do not include costs such as activation, maintenance and underutilization of the plants. Our dataset on price-quantity bids allows us to extract information at the unit level and to combine bids to obtain supply functions at the group level.

Let us denote with Γ_n the set of production units belonging to the n-th group, with $n = 1,\ldots,N$. Then, for any group n and each auction i in which a production unit belonging to group n was the price setter, we estimate the following equation:

$$p_i = b_0 + b_1 c_i + b_2 \frac{y(p_i)}{-y'(p_i)} + b_3 \frac{\bar{x}_i}{-y'(p_i)} + b_4 \widehat{F/f_i} + u_i, \tag{10}$$

where p is the marginal supply price bid (€) and c_i is the marginal cost (€) for the marginal unit i; $y(p)$) is the residual demand for group n defined as total market demand minus the supply offered by the competitors of group n at the marginal price. Positive residual demand at the equilibrium price implies that the quantity offered by unit i of group n is essential to satisfy demand whereas a negative value indicates that the unit is not essential to the market. The quantity $y'(p) < 0$ is the price derivative of residual demand around the market equilibrium[15] and u_i is an error term whose properties will be discussed below.

$F(c)$ and $f(c)$ refer to the probability distribution of the marginal costs that we estimated for each year in the range 2007–2010 following a parametric and nonparametric approach. Since the distribution of the marginal cost is roughly log-normal, we computed the sample mean and

14. REF-E is an Italian independent research center providing economic analysis and consulting on energy. The cost data they have courteously provided us with are those feeding their Elfo+ market simulation model. For details refer to Bosco et al. (2013).

15. We computed $y'(.)$ using a kernel estimator as in Bosco et al. (2012, Section 5).

variance of $\log(c)$ for each year and estimated $F(c)/f(c)$ as ratio of the resulting log-normal cumulative distribution function (cdf) and probability density function (pdf) computed at c_i. We have also estimated the same cdf and pdf 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 price-setting plant in each auction. Formally:

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

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 Euro 3.

The estimates resulting from the two different methods are similar, but we report only the parametric ones since some simulations have shown the nonparametric estimates to be more biased for large values of c_i.[16]

If we relate regression (10) to model (8), we are able to derive the following relationships:

$$b_1 = b_2 = 1, \qquad -b_3 = \alpha \cdot \beta \leq 1, \qquad b_4 = (1-\beta) \in [0,1],$$

so that $\beta = 1 - b_4$ and $\alpha = -b_3/(1-b_4)$.

Notice that for the group's profit-maximizing behaviour, the following restrictions on model (10) should hold

$$H_0^H : \beta = 1 \wedge \alpha = 1, \tag{11}$$

or in terms of the regression coefficients

$$H_0^H : b_4 = 0 \wedge b_3 = -1$$

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

$$H_0^G : \beta = 1 \wedge \alpha = 0, \tag{12}$$

or in terms of the regression coefficients

$$H_0^H : b_4 = 0 \wedge b_3 = 0.$$

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

Notice that in (8) 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:[17]

16. We thank an anonymous referee for bringing this issue to our attention. The simulation results are discussed in the on-line appendix.

17. 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

Table 2: Percentage Distribution of the Auctions in the Sample Used for Enel and in the Population

	Enel sample				Population		
	weekday	weekend	total		weekday	weekend	total
off-peak	49	23	73	off-peak	27	11	38
peak	16	12	27	peak	45	18	63
total	65	35	100	total	71	29	100

$$u_i = \mu_i + v_i$$

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

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

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

Due to the continuous evolution of the Italian market and the impact of the worldwide economic downturn that is likely to have influenced the electricity market performance in the second half of our sample, we run the regression for each year separately.

Results reported in this section refer only to Enel since data limitations (around 30 observations per year for Edison, the second largest producer) do not allow us to obtain reliable estimates for other firms. According to Bosco et al. (2012) Edison is found to behave as a profit maximizer while mixed results are obtained for Enel, for which the branch Enel Produzione does not appear to exploit completely its market power. Since our estimates are based only on auctions in which i) Italy is not split into zones, ii) a plant owned by Enel was marginal, the number of auctions we consider reduces to 2686 (some 8% of the total). We compare the distribution of our sample with that of the population with respect to the dichotomies weekday/weekend and peak/off-peak in Table 2: the day type in our sample is close to the actual (65% weekdays in our sample vs. 71% in the population) while off-peak auctions are over-represented (73% off-peak in our sample vs. 38%). This fact is not surprising as it is more likely that Italy does not split into zonal markets when the demand is not too high. Furthermore, the sample size decreases with time (from 1393 auctions in year 2007 to 281 in 2010) because of the reduced demand due to the deepest economic crisis since World War II, on one side, and the increase in the number and size of Enel's competitors, on the other side.

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*.

Table 3: Estimates of Model (8) for Enel and Tests on α and β

	2007			2008			2009			2010		
	Est.	S.E.	Prob.	Est.	S.E.	Prob.	Est.	S.E.	Prob.	Est.	S.E.	Prob.
c	0.460	0.116	0.000	0.274	0.129	0.034	1.288	0.221	0.000	0.848	0.403	0.036
$-y/y'$	7.280	0.222	0.000	0.629	0.058	0.000	0.615	0.059	0.000	0.579	0.051	0.000
$-\bar{x}/y'$	−1.102	0.239	0.000	−0.054	0.033	0.098	0.086	0.026	0.001	0.091	0.048	0.060
$\hat{F}/\hat{f}$	−0.012	0.007	0.065	0.013	0.007	0.054	−0.002	0.002	0.229	0.021	0.067	0.755
R^2	0.521			0.575			0.591			0.615		
df	1333			607			308			248		
	Est.	H_0^H	H_0^G	Est.	H_0^H	H_0^G	Est.	H_0^H	H_0^G	Est.	H_0^H	H_0^G
β	1.012	1.000	1.000	0.987	1.000	1.000	1.002	1.000	1.000	0.979	1.000	1.000
α	1.089	1.000	0.000	0.055	1.000	0.000	−0.086	1.000	0.000	−0.093	1.000	0.000
F-stat		1.734	11.518		418.440	3.399		893.820	6.422		255.470	1.834
p-value		0.177	0.000		0.000	0.034		0.000	0.002		0.000	0.162

The estimates of the fixed effect model for plants belonging to Enel are reported in Table 3. We do not report the random effect estimates since the Hausman test rejected its null at a 5% level for all years but 2009, and in this year the estimates are virtually the same.[18]

In two of the four estimates, the value of the marginal cost coefficient is significantly smaller than one, the value implied by our model. This downward bias is not surprising since our marginal cost is just a proxy of the real quantity, and in this error-in-variable regression the theory predicts a shrinkage towards zero of the coefficient of the variable observed with noise. However, this slight bias should not affect the coefficients of the other variables. In order to verify this conjecture, we tried to estimate the same four models by instrumenting the marginal cost variable using European gas prices in a two stage least squares framework.[19] Although the coefficients of the marginal cost did not improve much (gas prices are even worse as a proxy for marginal costs), all the other coefficients remained substantially the same, proving that our estimates are quite robust to the error-in-variable issue.[20]

Results indicate that the bidding behaviour of Enel Produzione changed significantly during the sample period. Since relevant regulatory reforms were not introduced in the years we analyse we interpret the changes of conduct as a reaction of the electricity generator to the new economic conditions emerging after the worldwide crisis which begun to hit the production level and hence the electricity demand starting from the middle of 2008.

In fact, our estimates for year 2007 appear to be consistent with model (10) and support the hypothesis of profit maximization at group level. In Table 3, β and α are jointly equal to one indicating that the H_0^H hypothesis of perfect group integration has to be accepted for year 2007. In this manner we give empirical support to the claim that vertical integration may explain supply price moderation found in Bosco et al. (2012). Individual dummies, reported in the on-line appendix, introduce idiosyncratic elements in the interpretation of the bidding behavior such as technology, location, maintenance, etc. For year 2007 we notice that carbon-fired units have an estimated intercept term higher than the other technologies.

18. The estimates of the random effect model can be found in the on-line appendix.
19. We thank an anonymous referee for his/her comments on the noisy measurement of the marginal costs.
20. The table with the 2SLS estimates can be found in the on-line appendix.

Estimates obtained for year 2008 show that the bidding behavior of Enel Produzione has evolved towards a new pattern characterized by a reduced degree of vertical integration. Indeed, the hypothesis of perfect group integration H_0^H is now rejected by the data while the hypothesis H_0^G is rejected at 5% level but accepted at 1% level of significance. This implies that the bidding strategy has become more aggressive so giving a greater emphasis on the defense of profits from the production activity. Higher prices requested from production units imply higher purchase cost for the retail branch. Similar results are confirmed for years 2009 whereas in 2010 the data support the hypothesis of perfect unbundling between production and retail. The null of profit maximization for the generator alone H_0^G is now supported by the joint test on parameters α and β.

During the sample period the impact of the crisis on the electricity market was substantial. The economic downturn reduced energy demand and reshaped the market supply function.[21] At the same time the introduction in the market of new production units[22] and of renewable technologies had a pro-competitive effect. The combined effect of these two independent events produced a flatter residual demand function for Enel starting from the middle of 2008 and for the remaining part of the sample period. We observed from the data a more aggressive bidding behavior on the part of Enel Produzione who asked higher bids for marginal production units (see also the price-cost margins calculated from Table 1). Gas fired plants were in fact running a number of hours per year lower than the break-even level and so they became unprofitable.

The strong impact that market conditions had on the CCGT technology during the sample period can be evaluated looking at the measure called spark spread, which is defined as the difference between gas cost for producing one kWh of electricity and the price of the kWh produced. It remained at a level of 15–20 Euro for years 2007 and 2008, which is considered optimal from the point of view of market operators, but then it collapsed at 10 Euro in 2009 and 6 Euro in 2010, so evidencing that the profitability of a marginal plant tends to zero. Higher bids with respect the ones implied by a fully integrated group strategy are now requested to reach a balance between costs and revenues from the production activity of thermal units.

On the basis of the above discussed perspective, the declining value of α can be interpreted as a signal that the generator, who actually places the bid, is exploiting its informative advantage to contrast the sharp decrease of the profitability conditions of its company. We can guess that this behavior is not entirely opposed by the Headquarter who cares about the long-term sustainability of its investments in generation capacity.

4. CONCLUSION

This paper addressed the question of how the supply conduct of a vertically integrated power producer can be coordinated in a wholesale market with the buying activity of a downstream retailer. Since vertical integration is recognized to reduce market power of dominant firms when they act as a part of a group, we introduced a simple Principal-Agent model to describe price coordination between branches belonging to the same group in the presence of asymmetric information about generation costs. Asymmetric information impedes to the holding firm to fully control the behavior of the production branch which, in the absence of an incentive, would behave in an

21. In 2009 total purchases registered in the MGP were subjected to a significant reduction with respect to year 2008 (-6.7%) A similar reduction in electricity demand has been experienced in Italy in the post-war period only.

22. In year 2009 a total of 2000 MW of new capacity became operational in the market. In particular, 1353 MW were from thermo production whereas 656 MW from renewables.

opportunistic manner raising equilibrium prices in the market to its own advantage. However, higher equilibrium prices reduce profits of the retail branch which buys electricity in the wholesale market and sells it to customers at fixed prices. In our model the parent company is able to coordinate the activity of the producer through an incentive mechanism which requires a money reward guaranteed to its management. Tests of model's predictions indicate full, partial and no vertical integration depending on parameters estimates. In general partial or no profit maximization at group level 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), but lower than those corresponding to a pure profit maximization at generation level.

Empirical tests have been conducted using Italian data of Enel, which, at least in the two initial years of the sample, was the pivotal player in the market. Results show that the behavior of Enel Produzione changed during the sample period starting from a bidding conduct in line with the hypothesis of profit maximization at group level (full integration between production and retail branches) in 2007 and then evolving towards profit maximization of the production branch alone from 2008 to 2010.

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