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# The Ideal Competitive Electricity Market. A simulation for Italy

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**Abstract**

Liberalization in the electricity markets has been characterized by oligopoly conditions and exercise of market power, largely studied in the empirical literature on the supply side. This paper provides a new contribution to the literature on the electricity market presenting a theoretical and empirical model to construct a competitive equilibrium, estimating market power both on the supply and demand side of the day-ahead electricity market. This model provides a useful analysis tool for the policy-maker to implement pro-competitive regulation, explicitly measuring the welfare loss associated with non-competitive market conditions. Results show the effect of non-competitive equilibria for the hourly markets in the period 2013-2014. In an ideal competitive market, prices would be lower than historical prices by about 2-5% and quantities would be higher by about 0.5-1%.

*Keywords:* electricity market, competitive equilibrium analysis, market power, oligopoly, residual demand and supply function, oligopsony, dead weight loss.

*JEL:* codes: D01, D43, L13, L81, Q41

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## 1. Introduction

The electricity market reforms of the 80's and 90's aimed at establishing a competitive behavior among suppliers and purchasers, promoting a new general pro-market environment, unleashing new and more efficient technology developments in the generation sector, building new awareness and consciousness of consumers. These reforms gradually abandoned the previous organization of vertically integrated monopolists and Government owned companies establishing a new market design with the Day Ahead Market (DAM) characterized by an implicit auctions mechanism and the ancillary markets for network security services. *The market design assumes that electricity generation can be ranked in implicit auctions.* In the DAM we assume that a Walrasian auctioneer ranks bids of every suppliers(purchasers) according to an efficient merit order, forming a stepwise supply(demand) function to determine the price and quantity exchanged as intersection between the two curves. The resulting equilibrium price (the system marginal price SMP) is paid by purchasers to all dispatched suppliers.

The auction mechanism was inspired by the idea that set competition in the market would increase the social welfare reducing the final price for consumers. Unfortunately, the first deregulation experiences showed how many organized electricity markets in Europe and USA are affected by anticompetitive behavior, especially on the supply side (Bosco et al., 2012). These markets are characterized by the existence of large generation companies, which established oligopoly conditions, with the exercise of market power as largely studied in the empirical literature (Green and Newbery, 1992; Anielski et al., 2002; Wolak, 2003; Boffa et al., 2010). Recently, empirical evidence of the existence of oligopsony market power has emerged in Bigerna and Bollino (2014).

The aim of the paper is to provide an empirical measurement of the welfare dead-weight loss of welfare due to the strategic behaviors in both the market sides. To this aim, we develop a comprehensive model of analysis to compare competitive and non-competitive equilibria caused by agents exercising market power. We measure the deviation from the competitive equilibrium and the corresponding welfare loss as follows. First, we develop an empirical measure of market power; second, we construct a counterfactual market auction building the aggregate demand and supply curves from bids purged by market power; third we derive the implied theoretical competitive equilibrium[1]. The total welfare loss is computed as the difference between the simulated competitive welfare and the welfare derived from the current market equilibrium.

This computation requires to tackle several issues as noted in the literature. In a sealed bid price auction the identification of the best strategic response of each agent (the Best Equilibrium Function - BEF) may be impractical if we do not observe the distribution of all the scheduled bids (Athey and Haile, 2006). Using unit plant bid data allows to overcome this issue and to compare the actual bidding behavior to the theoretical competitive benchmark (Hortacsu and Puller, 2008). Indeed, the first order condition maximizing the expected profit depends on a random component capturing the extent of market power, that is the shift in the probability of the clearing price due to change in the best response conditional on the competitors' best bids. Observing the empirical distribution of all the bids allows to recover this probability distribution, identify the best response for each agent and derive a measure of unilateral market power (Wolak, 2003), which is the Lerner index. This latter index can be correctly computed when there are transmission congestion, as shown by **?**.

In this respect, this paper offers three new contributions to the literature. First, unlike the literature that traditionally uses market aggregated data, we use simultaneously the hourly disaggregated bid data at the individual level for both suppliers and traders to construct the supply and demand curves. Second, we relax the assumption of price-taking behavior on the demand side. This

[1] The competitive behavior analysis is a common method to evaluate market inefficiencies. This method has been primarily used to evaluate the mark-ups (for example see Wolfram (1999); Joskow and Kohn (2002) and Mansur (2008)) and then applied to measure the welfare loss (for example, see Borenstein et al. (2002)).

paper instead assumes that strategic agent can affect market outcomes on both market sides. Third, we estimate and compute the deviation of the equilibrium prices and traded quantities from their competitive values, disentangling the two main components: the oligopolistic behavior effect on the supply side and the oligopsonistic effect on the demand side. In this way, this analysis shows how much of the current welfare would increase if a competitive market structure would be applied in both market sides.

Empirical results that deviations from the competitive welfare are significant and the removal of the oligopsonistic market power highlights the major increase in welfare. In addition, we decompose the current welfare in its producers and consumers' components and simulate how the shares would change if a competitive structure were applied. *Both components are significant confirming the need to undertake the analysis of both market sides.* The paper proceeds as follows. Section 2 briefly discusses some related literature. Section 3 presents the Italian electricity market structure. Section 4 shows the theory and the methods applied. Section 5 presents the results and discussion. Section 6 presents the conclusions and the policy implications. Appendix A presents the robustness analysis on the econometric estimation procedure.

## 2. Related Literature

In the uniform price auction electricity market agents submit their bids (the block of electricity to be sold or purchased and its corresponding price) in order to maximize their profits. Electricity suppliers may increase their profits if they are able to affect market equilibrium through their decisions on output level and price bid.

There are two main approaches to model the uniform price auction mechanism and to analyze its inefficiencies): the Supply Function Equilibrium (SFE) and the Optimizing Bidding Behavior (OBB).

The SFE, first proposed by Klemperer and Meyer (1989), is frequently used in determining market power under the assumption that the generation costs are known. Subsequently, Bolle (1992) applied their model to the British electricity spot market, analyzing the possibility of tacit collusion. He concluded that if suppliers coordinate on bidding the highest supply function, a decrease on market concentration does not necessary implies a decrease in aggregated profits. Green and Newbery (1992) excluded the tacit collusion supporting instead the hypothesis of unilateral market power using as an example the British electricity spot market. Other theoretical contributions have implemented the model incorporating other assumptions. Newbery (1998) extended the model to the case of contracts; Holmberg et al. (2013) assumed as usual constant marginal costs but he relaxed the symmetry assumption retrieving a piece-wise SFE.

Alternatively, the OBB approach describes the market outcomes highlighting the withholding strategy of a multi-unit supplier. In this case bidders may shade their real valuations inflating their auction bids after the first to increase their revenues for all infra-marginal units (Wilson, 1979; Wolfram, 1999; Athey and Haile, 2006).

For the uniform price auction market Guerre et al. (2000) proposed a model under assumption of expected profits maximization that characterized the Bid Equilibria Function (BEF). from this is possible to retrieve the marginal cost function and the Lerner Index[2].

Among the application of the OBB model there are Wolak (2003) and Cramton (2004) that use the residuals demand elasticity to compute the Lerner index in the electricity market.

Bolle (2001), in a game theoretic analysis of competition, distinguishes two type of agents: non-eligible customers covered by the Single Buyer and big industrial users relatively free to switch on and off their electricity device and to

[2]Suppliers owning more that one unit plant are likely to shade their real valuation applying a withholding strategy and inflate their bids after the first to increase revenues for all the infra-marginal units dispatched. In the Stackelberg model we have to mention also the externality effect of the peak load unit's bid: the mark-up on the peak load costs positively influences the profits obtained in base-load unit (Parisio and Bosco, 2003).

post-pone their electricity consumption. In this framework, Hortacsu and Puller (2008) introduced uncertainty in a non-cooperative game. The uncertainty rises from the fact that each supplier selects its bidding strategy conditional on the strategies selected by all other competitors. the comparison between the actual bidding strategy and the competitive benchmark is a measure of market power.

In this framework, Hortacsu and Puller (2008) introduced of expected model maximizing bidding behavior. The uncertainty rises from the fact that each supplier selects its bidding strategy conditional on the strategies selected by all other competitors. Assuming a non-cooperative game, the comparison between the actual bidding strategy and the competitive benchmark is a measure of market power.

The same approach was used by Bosco et al. (2012) for the Italian Electricity Market deriving the Lerner index of the main generation companies using market clearing price data and the estimates of the marginal cost functions.

Following the OBB framework, this paper focuses on the units' bids of both suppliers and purchasers, avoiding restricted assumptions on the marginal cost function. In this contest the BEF is univoquely identified since all the bids are independent (Athey and Haile, 2006). Operationally we use unit specific bid data for suppliers and purchasers measuring both oligopolistic and oligopsonistic market power. For each agent, the empirical residual demand(supply) curve can be derived to compute the Lerner index, that is the mark-up(mark-down) with respect to the competitive bid (Wolak, 2003; Bigerna and Bollino, 2014).

Subsequently we compare the actual market equilibrium with the theoretical competitive simulated outcomes to measure the welfare loss in accordance with the competitive benchmark approach (Wolfram, 1999; Joskow and Kohn, 2002; Mansur, 2008). Borenstein et al. (2000) and Borenstein et al. (2002) used market-level data (the market-clearing prices and quantities traded) to estimate the suppliers' market power in the restructured California electricity market. First, they simulated the industry marginal costs and the competitive market where no generator has the ability to exercise market power, second, they compared the simulated prices with the actual prices using the Lerner Index computed at the industry level. Joskow and Kohn (2002) implemented this simulation model to estimate the marginal costs taking better account of emission allowance costs. The benchmark approach is effective to evaluate the welfare loss and the discrepancy of output outcomes from the competitive ones, but it is less informative about the specific manifestations of market power. However other inefficiencies may impact the market outcomes as highlighted, among others, by Harvey and Hogan (2002), such as start-up and minimum load costs, emission allowances, environmental constraints, outages, hydro power availability degree of vertical integration and transmission congestion. For the Italian market this issue has been considered by Boffa et al. (2010) **?** Sapio and Spagnolo (2016) who highlighted the relevance of transmission constraints on the rise in electricity price.

## 3. Market Structure

The reform of the Italian market started in 2004, to pursue a pro-competitive market structure, imposing to the state-owned monopolist (ENEL) to become private, to sell its shares to public and to sell part of its generation capacity to newcomers. Most of the transactions of purchase and sale of electricity is hosted in the DAM, that is a wholesale electricity market, where hourly blocks of electricity are negotiated and where prices, volumes, injection and withdrawal schedules are defined for the next day. Since 2005, DAM became fully operational with participation of almost one thousand main generation units on the supply side and about hundred purchasers on the demand side such as big industries, trader retailer and high energy intensity company together with Single Buyers, the state company guarantying to cover the demand of non-eligible customers. Despite the high degree of market participation, concentration remains a permanent characteristic of DAM on both sides of the market [3], as shown by

[3]Energy Authority uses the traditional Herfindhal index to monitor the market concentration and pursue a pro-competitive market surveillance mechanism discouraging suppli-

the Herfindahl index in Table 1.

[Table 1 here]

We assume that unilateral market power may be exercised by the main operators trading the larger quantity of hourly electricity (See Appendix). The other participants constitute the competitive fringe.

The Italian power system is divided by the Transmission System Operator (Terna) and the market operator (GME) into portions of transmission grids ("zones"). When the equilibrium quantity is greater than the grid capacity constraints, a potential danger of security would arise. Therefore, market segmentation in two adjacent zones occurs with different zonal system marginal price (SMP): one exporting zone, upstream of the constraint with a lower price, and one importing zone, downstream of the constraint with a higher price. The suppliers are paid by the zonal SMP while purchasers paid the National Single Price (PUN), that is the average of zonal SMPs weighted for the quantity. Different market configurations have occurred in the period considered (Table 2).

[Table 2 here]

Notice that the majority of two market configurations concerns the separation between Sicily and the mainland Italy due to the bottleneck of an old transmission line. The construction of the new Sorgente-Rizziconi undersea electrical cable has substantially removed this bottleneck in 2016, creating the technical conditions to avoid the market splitting[4]. For all these reasons, we use as the empirical data of our analysis all the hours in which there occurs a single market or a split of Sicily from Mainland. These are about 64% of the total hours in the period, as shown in Table 3.

ers withholding strategy. Time series of Herfindal index classified by peak/off-peak hours and zones are available under request or they can be found in the GME internet site: www.mercatoelettrico.org.

[4]See Sapio and Spagnolo (2016).

[Table 3 here]

## 4. Theory and Methods

### *4.1. The theoretical model*

Unit level bids allow to derive for each agent the empirical residual demand (supply) curve, to univoquely identify its BEF and to directly compute the residual demand (supply) elasticity. In this framework, the inverse of this elasticity can be though as the Lerner index measuring the incentive to bid below/above the competitive benchmark.

We assume the standard Cournot model considering two categories of operators: those agents with significant market shares and a competitive fringe with small market share treated as price-takers, including non-market based agreements.

We apply the OBB model where each supplier submits a bid to maximize its profits function given its marginal cost curve, its expectations about market demand, and its expectations of the supply curves of the other bidders. Therefore, in making this decision on the quantity to supply at all relevant prices, the supplier needs to estimate the residual demand curve, that is the difference between the aggregated demand and the supply provided by all others competitors at all possible prices. Suppliers can optimize their financial positions, usually weeks or month in advanced, by means of financial contracts, hedge contracts or contracts for differences. Financial contracts are usually used to reduce the market price risk and they imply that a certain amount of electricity is hedged and is not subjected to the market price.

Let $p_h = f(Q_h)$ be the inverse electricity market demand at time $h$ with $Q_h = \sum_{j \neq i} q_{jh} + q_i$ being the aggregated quantity supplied by the firm $i$ and by all competitors. Each supplier $i$ wants to maximize the profit function:

$$\pi_{ih}(q_{ih}) = p_h(\mathbf{Q}_{-ih}; q_{ih})q_{ih} - [(p_h(\mathbf{Q}_{-ih}; q_{ih}) - p_C)q_{iC}] - C(q_{ih}) \qquad (1)$$

where:

- $p_h(\mathbf{Q}_{-ih}; q_{ih})$ is the DAM inverse demand function depending on the quantity set by firm $i$ and quantities set by the other competitors represented by the vector $\mathbf{Q}_{-ih}$;
- $q_{iC}$ is the quantity exchanged with forward contracts;
- $p_C$ is the price of forward contracts;
- $C_i(q_{ih})$ is the firm's cost function.

The optimal bidding quantity is given by the output level at which the marginal revenue associated with that period's demand realization equals the supplier's short-run marginal cost.

Assuming that all competitors simultaneously maximize their profit a la Cournot choosing an output level belonging to their reaction function, we can derive the vector of the BEF of all competitors of i as: $\mathbf{Q}^{\star}_{-ih}$.

By substituting back into the inverse demand function, we obtain the residual demand faced by suppliers $i$: $RD_{ih}(p_h) = D(p_h) - \sum_{i \neq j} q^{\star}_{jh} = D(p_h) - Q^{\star}_{-ih}$ where each $q^{\star}_j$ is the best reply choice of each competitor for any level of price, $Q_h$ is the aggregated market demand and $Q^{\star}_{-ih}$ is the overall supply of competitors thought as the sum of all the optimizing competitors' quantities. The first term in (1) is the revenue received by supplier $i$ for selling energy in the DAM. The middle term is the payment made (received) by supplier $i$ if the DAM price exceeds (is inferior) to the contract price. The last term is the operating cost to produce the electricity sold in the DAM.

Forward financial contracts settle through the difference payments between the contract buyer and seller. Under this scheme, each short-term market supplier simply pays for all energy produced at the short term market price; forward financial arrangement need not to be known to market participants.

As the magnitudes $p_c$ and $q_{iC}$ are set in advances of the actual DAM bidding process, following (Wolak, 2000) we rewrite the objective function to be maximized as the variable profit (the net profit excluding fixed costs) as follows:

$$\pi_{ih}(q_{ih}) = q_{ih}[p_h(Q_{-ih}; q_{ih}) - MC_{ih}] - [ph(Q_{-ih}; q_{ih}) - p_C]q_{iC} \qquad (2)$$

showing the impact of the hedge contract position on the optimal bidding behavior. Equation (2) shows that unless the bidding strategy of supplier $i$ can affect the market clearing price, the profit is not affected by its bidding strategy for a given hedge contract price and quantity. Because $p_C$ and $q_{iC}$ are set in advance of the DAM bidding process and marginal cost is known, the second term of (2) is fixed and therefore the supplier $i$' maximizes only the first term of (2).

Defining $q_{Cih}(p_h) = q_{ih}(p_h) - q_{iC}$ as the net of contract cover residual demand faced by firm $i$ [5], the portion of profits that are affected by the DAM bidding strategy can be written as:

$$\pi^{\star}_{ih}(q_{Cih}) = [p_h(Q_{-ih}; q_{Cih}) - MC_{ih}]q_{Cih} \qquad (3)$$

Showing that only $q_{Cih}$ is the only relevant quantity determining the incentive of the suppliers to drive the market price.

Formally, the profit maximization problem faced by supplier $i$ becomes to choose:

[5]In the Cournot model, agents optimize taking as given the strategy of other competitors, that is, $Q^{\star}_{-ih} = \sum_{j \neq i} q^{\star}_{jh}$ and that the best response quantity with and without contract cover are respectively: $q_{ih} = RD_{ih}(p_h)$ and $RD_{Cih} = RD_{ih}(p_h) - q_{iC}$. The line shifted to the left parallel to $RD(p_h)$ is the firm $i$'s residual demand less the contract cover $q_{iC}$. Associated with the both $RD_{ih}(p_h)$ and $RD_{Cih}(p_h)$ are the marginal revenue function, $MR_{NCih}(p_h)$ and $MR_{Cih}(p_h)$ respectively. From the standard economic theory, the intersection of the marginal cost with each marginal revenue function gives the best response quantities with and without contract cover. When firm holds contract cover, the best response quantity sold to the spot market is higher than the quantity firm would sell if it did not. Therefore, the corresponding best response price with contract cover will be always lower than the best response price without contract cover. The fundamental determinant of the optimal amount of contract cover is the elasticity of the residual demand curve. The steeper is the residual demand the smaller will be the divergence between the firm $i$'s best response quantities with and without contract cover and the greater will be the divergence between the two prices associated with the two best responses.

$$q_{Cih} = argmax\,\{\pi_{ih}(q_{Cih})\} = [p_h(Q^{\star}_{-ih}, q_{Cih}) - MC_{ih}]q_{Cih} \tag{4}$$

Applying the first order condition we derive the identity:

$$\frac{\partial \pi_{ih}}{\partial q_{Cih}} = \left[\frac{\partial p_h}{\partial Q^{\star}_{-ih}} \frac{\partial Q^{\star}_{-ih}}{\partial q_{Cih}} + \frac{\partial p_h}{\partial q_{Cih}}\right] q_{Cih} + p_h - MC_{ih} \tag{5}$$

where $\frac{\partial Q^{\star}_{-ih}}{\partial q_{Cih}}$ is the conjectural variation that represents the belief of supplier $i$ about how its competitors will react as it changes its own output. The vector of conjectural variations represents the slopes of the competitors' reaction functions, which is zero in the Cournot model: $\frac{\partial Q^{\star}_{-ih}}{\partial q_{Cih}} = 0$ for each $i = 1, .., N$. From the first order condition we derived the identity[6]:

$$\frac{p_h - MC_{ih}}{p_h} = \frac{\partial p_h}{\partial q_{Cih}} \frac{q_{Cih}}{p_h} = \frac{1}{\epsilon_{RD_{Cih}}} \tag{6}$$

where $\epsilon_{RD_{Cih}} = \frac{\partial q_{Cih}}{\partial p_h} \cdot \frac{p_h}{q_{Cih}}$ is the elasticity of the residual demand function faced by firm $i$.

Rearranging the equation allows measure the market power exercised by each player using the Lerner index ($LS_{ih}$) derived as the inverse of the residual demand elasticity faced by firm $i$ in hour $h$:

$$LS_{ih} = \frac{p_h - MC_{ih}}{p_h} = \frac{1}{\epsilon_{RD_{Cih}}} \tag{7}$$

[6]It is important to note that the value $\frac{1}{\epsilon_{RD_{Cih}}}$ measures the incentive of the suppliers to raise market price by withholding output, not the supplier's ability to do so given by $\frac{1}{\epsilon_{RD_{ih}}}$. These two concepts differ due to the fixed-price forward market obligations that may reduce the incentive. If short term market prices are expected to be higher than the contracts fixed-prices and the contracts quantity is higher than the energy sold to short term market, supplier has not incentive to withhold output and raise market price since it would cause a loss equal to $[(p_h(Q_{-ih}; q_{ih}) - p_C)(q_{iC} - q_{ih})]$. The ability and the incentive to raise market price are linked through the formula:

$$\frac{1}{\epsilon_{RD_{Cih}}} = \frac{1}{\epsilon_{RD_{ih}}} \left[\frac{RD_{ih} - q_{iC}}{RD_{ih}}\right]$$

The right-hand side term is the inverse elasticity of the usual residual demand measuring the ability to withhold output in order to raise the price; the left-hand side term is the inverse elasticity of net residual demand (excluding the contract quantity) that measures the incentive to withhold output in order to raise short term market price.

The shape of the residual demand curve depends on the size of the individual supplier. Typically as large the supplier as steeper is its residual demand curve and greater is its Lerner index.

In the Italian Electricity market, the forward contracts are not much developed. They are sold in the Italian forward electricity market (MTE) but unobservable. Following Reguant (2014), it can only be assumed that agents hedge a given percentage of their output. Empirically, we find that the overall quantity traded in the MTE was about the 3.86% in 2013 and the 9.90% in 2014 of the total electricity sold in the day-ahead market. For this reason, we infer that the inverse elasticity of the residual demand curve $RD_{ih}$ slightly overestimates the incentive to raise market price.

Symmetrically, to what we did in the supply side, we derive the Lerner index in the oligopsony market starting from the optimizing strategy applied by purchasers. Conventionally variables of demand side of market are denoted with superscript $D$. Formally, the usual profit maximizing model for the oligopsony is:

$$q^D_{Cih} = argmax\pi^D_{ih}(q^D_{Cih}) = zx_ip_h(Q^{D\star}_{-ih}; q^D_{Cih})(q^D_{Cih} + q_C) + p_C q^D_{iC} \qquad (8)$$

where:

- $z$ is the price of output $x_i$
- $x_{ih} = f_i(q^D_{ih})$ is the production function;
- $p_h = (Q^{D\star}_{-ih}, q^D_{ih})$ is the aggregate supply function of electricity in the wholesale market;
- $Q^\star_{-ih}$ is the sum of best demands of all other participants except $i$;
- $q^D_{Cih}$ is the DAM demand with contract cover of buyer $i$;
- $q^D_{iC}$ is the quantity purchased with forward contract;
- $p_C$ is the price of forward contract.

Under the forward contract settlement scheme, the short-term market purchaser simply charges for all energy withdrawn from the network at the short-term market price. As $p_C$ and $q_{iC}$ are set in advance, the purchaser $i$'s day-ahead bidding strategy has no impact on the last term of (8) and its goal in setting prices and quantities is to maximize only the first two terms of (8). Recalling that the residual supply $RS_{Cih} = q^D_{Cih} = q^D_{ih} - q^D_{iC}$ is the best response quantity purchased with contract cover, the first order conditions for buyer $i$ are:

$$\frac{\partial \pi(q_{Cih})}{\partial q^D_{Cih}} = z\frac{\partial f_i(q^D_{ih})}{\partial q^D_{ih}}\frac{\partial q^D_{ih}}{\partial q^D_{Cih}} - \left[\frac{\partial p_h}{\partial Q^{D\star}_{-ih}}\frac{\partial Q^{D\star}_{-ih}}{\partial q^D_{Cih}} + \frac{\partial p_h}{\partial q^D_{Cih}}\right] q^D_{Cih} - p_h \tag{9}$$

where $\frac{\partial Q^{\star}_{-ih}}{\partial q^D_{ih}}$ is the firm's input conjectural variation with respect to the industry total factor demand. In a Cournot oligopsony model, buyers take as given the demand of other competitors, implying that the conjecture is of no reaction and, therefore, $\frac{\partial Q^{\star}_{-ih}}{\partial q^D_{ih}} = 0$ for each $i = 1, .., N$. From the first order conditions, we derived the identity:

$$\begin{aligned} LD_{ih} &= z\frac{\partial f_i(q^D_{ih})}{q_{ih}} - p_h \\ &= \frac{z\frac{\partial f_i q^D_{ih}}{\partial q^D_{ih}} - p_h}{p_h} \\ &= -\frac{\partial p_h}{\partial q^D_{ih}}\frac{q^D_{ih}}{p_h} \\ &= \frac{1}{\epsilon_{RS_{ih}}} \end{aligned} \tag{10}$$

where $\epsilon_{RS_{ih}}$ denotes the elasticity of the residual supply facing buyer i in hour h. $LD_{ih}$ is, therefore, the inverse of this elasticity and represents a Lerner measure of the buyer's markdown over the WTP, i.e., a measure of the unilateral market power of buyer $j$ [7]. The elasticity of residual supply incorporates all relevant information to characterize how a change in buyer $j$'s quantity would change

[7] Even for the demand side we should differentiate the ability to low the input price from the incentive to do it. The index we derived refers to the residual supply inverse elasticity without contract cover, that, as we said before, overestimates the incentive to low the price of a percentage equal to $(RS_{Cih} - q_{iC})/RS_{Cih}$.

the market price by affecting the behavior of other buyers. The residual supply curves faced by fringe buyers are supposed to be vertical, inhibiting the exercise of market power and involving a zero Lerner.

Since market demand and supply curves (and the corresponding residual demand and supply curves) are step function, computing the elasticity at a given point requires the finite difference approach using the following formula (Wolak, 2003):

$$\begin{aligned}\epsilon_{Fih} = & \frac{RF_{ih}(p_h(high)) - RF_{ih}(p_h(low))}{p_h(high) - p_h(low)} \quad \times \\ & \frac{p_h(high) + p_h((low)}{RF_{ih}(p_h(high)) + RF_{ih}(p_h(low))}\end{aligned} \tag{11}$$

Where $F = D; S$ denotes the demand and supply step function respectively, $RF_{ih}(p_h(high))$ and $RF_{ih}(p_h(low))$ are respectively the quantities' lower and upper bounds of the steps of the residual curve, as $p_h(low)$ and $p_h(high)$ are the prices lower and upper bounds.

This market design entails several important implications: (i) the mark-up between the profit maximizing bid and the marginal cost increases with the quantity that the bidder is supplying; (ii) the lower is the competitors' supply elasticity the larger is the spread between its optimal bid and marginal cost; (iii) the greater is the incentive for larger bidders to inflate bids above marginal cost implies a short run inefficiency the smaller will be the market is served by the largest bidders. Moreover, a supplier that inflates bids above marginal cost does not have unlimited power to charge whatever he wants. The supplier's bids are limited by the competitive response of other suppliers as well as the price responsiveness of the aggregated demand. As the supplier raises its price it runs an increasing risk that either another supplier will step in to serve demand or that buyers will curtail demand. At the same time, the response by demand and other suppliers is not unbounded. Demand may have a limited ability to curtail quantity in response to higher prices and other suppliers may be limited in their ability to step in to meet demand. These limits imply that suppliers are not price takers, but face a marginal trade off between the marginal gains from a higher bid curve against marginal losses from foregone output. The same line of reasoning applies on the demand side.

### *4.2. Empirical Methodology*

We construct the aggregate market supply and demand functions, designing a five-step procedure using the individual bid of the market participants. First, we have divided the sample distribution of the recorded prices in 30 quantiles (i.e., price observations are divided in 30 groups of the same size) in every year. The cutoff point of each quantile is used as the break point for aggregating the supply and the demand into step functions for every hour. Given that there are on average about 50 bids on the demand side and 200 bids on the supply side, the 30-step function market demand is an acceptably accurate approximation of the true market behavior [8].

Second, we controlled for the effects of the fringes by subtracting their aggregate quantities from the market curves at any given market price; the resulting curves are the net demand and the net supply faced by Cournot price-maker suppliers and buyers, respectively.

Third, we constructed the residual demand and supply curves for each agents, applying the Cournot OBB model to derive its BEF.

Fourth, for each strategic agents, we recovered from the BEF the LS and LD, given by eqs (7) and (10), respectively, recorded at the price interval corresponding to the quantile where the market clearing price lies, using the formula of arc elasticity given by eq. (11). In this way, we obtain for each player, an empirical distribution of Lerner Index as a function of the price level[9].

Fifth, following Cramton (2004), we use the derived mark-up(mark-down) to correct the price bid submitted by each firm in the supply(demand) side. As done by a Walrasian auctioneer, we re-order the corrected bids to sell(purchase)

[8] We follow Holmberg et al. (2013) who argue in favor of approximating step-functions by smooth differentiable functions in economic analysis, provided that the step number is adequate.

[9] Results are available upon request.

to construct a new merit order ascending(descending) and we recover the supply(demand) curves to derive the new market equilibrium. This new equilibrium is the intersection of the simulated demand and supply derived from a competitive behavior and, therefore, it can be seen as the competitive equilibrium that would prevail when agents could not exercise unilateral market power.

To give an example of this methodology, consider that on the supply side of the market the average $LS_{ENEL}$ for ENEL is 10% at the price level of 50 euro and 15% at the price level of 60 euro. We estimate $LS_i$ and $LD_j$ for each firm i and buyer j and use these computed values to correct each players' price bid with the estimated Lerner index referring to that price level. For instance, in the above-mentioned case of ENEL the bids in the 50-euro/MWh range have been corrected downward by 10% and all the bids in the 60 euro/MWh range by 15%. Analogously, we have corrected the bids of all agents both on the supply and demand side.

Sixth, note that on the supply side, we have estimated an empirical threshold, set at 30 euro/MWh, that would represent the short run marginal cost incurred by a typical CCGT unit. This threshold was derived as the average difference between the zonal SMP and the Clean Spark Spread (the average spread between the zonal price of electricity sales and the variable cost of a plant CCGT located in the South zone which is the area that recorded the lowest price). Assuming that bids below this threshold are truly competitive, i.e. they reflect the true marginal cost, while bids above this threshold reflect a strategic behavior of profit maximizing exercise of market power, we have applied the correction only to bid above this threshold. The correction of the bids of all the main suppliers and purchasers refers to the hours of the period 2013-2014.

Subsequently, we have used these new bids to simulate the ideal competitive market. We have done this in two steps (Figure 1). We label $S_0$ and $D_0$ the historical supply and demand functions and $S_1$ and $D_1$ the simulated functions.

[Figure 1 here]

The original historical equilibrium price is at point A. First, we have corrected the bids to remove only the supply strategic behavior. We have recomputed the merit order and the SMP. This entails a reduction (or non-increase) of the equilibrium SMP, with respect to the historical SMP, at point B, because the aggregate supply function can only shift downward from $S_0$ to $S_1$ (or remains unchanged). The interpolation of the adjusted suppliers' bids near the new equilibrium allows to derive the slope and the intercept of the new supply curve. Second, we have also removed the demand strategic behavior, which entails the upward (non-downward) shift of the demand curve from $D_0$ to $D_1$. The slope and the intercept of the new demand function were estimated using the interpolation procedure. The new SMP was then derived at point C, at the intersection of the two simulated curves $S_1$ and $D_1$. This is the estimated competitive equilibrium, which we deem to represent the realization of the ideal competitive electricity market.

The comparison of the two alternative equilibria (points B and C in Fig. 1) to the historical outcome (point A) allows to evaluate the loss in efficiency measured in term of social welfare. We are interested to investigate how much the strategic behaviors affect the total welfare and which are their re-distributive effects. We computed the social welfare resulting from the different market outcomes as the sum of producer and consumer surplus. Moreover, we computed the weights of the producer and consumer surplus on the total welfare showing how these percentages change when we remove first the oligopolistic and then the oligopsonistic market power.

Consumer surplus is the difference between what purchaser are willing to pay for electricity relative to the current clearing price. The consumer surplus is computed in two different ways. First, we assume that the maximum willingness to pay is the institutional price-cap imposed by the Energy Authority equal to 3000 euro/MWh; the corresponding consumer surplus is measured as the area below the downward-sloping demand curve and above the equilibrium market price (depicted with a horizontal line drawn between the y-axis demand curve). Second, we consider the maximum willingness to pay as given by the maximum accepted price bid in each hour. In this case the resulting consumer surplus is smaller than in the previous case, because the vertex of the area below the demand curve (the maximum price accepted) will be usually lower than the price-cap. In both the cases, consumer surplus increases as the equilibrium price falls and vice-versa.

The producer surplus is the extra-profit gained when the market price is higher than the marginal cost of production. Graphically, the producer surplus for all suppliers in the market is the area below the equilibrium price line and above the aggregated supply curve. The size of the producer surplus increases as the market price increases and vice-versa.

## 5. Results and Discussions

We summarize the estimation results in Table 4. We show the average historical equilibrium prices, quantities and social welfare (col. 1), their changes in case of correction to remove market power on the supply curves (col. 2), on demand curves (col. 3) and the total effect (col. 4).

Results in Table 4 highlight that the market power exercised in both supply and demand sides mainly affects the clearing prices rather than the quantities traded: while quantities increase by 0.77%, the clearing prices fall by 3.29%. These relative magnitudes reflect the empirically estimated low level of elasticity of both supply and demand curve.

The deviation from the competitive equilibrium is decomposed in two components, suppliers and purchasers strategic behavior effect. Note that oligopolistic strategic behavior affects more the market equilibrium than oligopsonistic one. Removing only the oligopolistic market power implies a decreases by 5.88% and by 3.16% in 2013 and 2014 respectively, while the increase in the quantities traded is marginal. On the other hand, when we adjust the purchasers' bids to remove their oligopsonistic market power, the changes in the clearing prices are meaningful but lower, on average 1.33%.

The effects are more pronounced in 2013 that 2014. In 2013, prices are lower on average by 4.58%, while the equilibrium quantities are higher average by 0.96%. In the 2014 instead, prices are lower by 2.01% and quantities are higher by 0.59%.

[Table 4 here]

There is not a well-defined pattern if we distinguish the results between peak (from 8 a.m to 7 p.m.) and off-peak (from 8 p.m. to 7 a.m.) hours. Looking at the figures for the 2013 and 2014 (Table 5-6), the supply side market power affects more the off-peak hours' equilibrium values where the deviations from the competitive equilibrium are slightly larger than those referring to peak-load periods. Even if oligopsonistic effects seem larger during peak hours, they do not affect the overall pattern in both years. The effect of purchasers' strategic behavior shows that they may reschedule their withdrawing programs during peak hours when the probability of congestion is higher.

[Tables 5-6 here]

When we gradually remove the market power, the welfare gradually increases, and the total average growth lies between the 0.55% in 2013 and the 0.39% in 2014 (Table 7). Decomposing the overall market power effect in the oligopolistic and oligopsonistic one, the increment on total welfare due to override the suppliers' market power is negligible, ranging between the 0.19% and the 0.07%, while the increase in social welfare due to wholesalers' strategic behavior is larger, lying between 0.31% and 0.36%.

Moreover, Table 7 shows the decomposition of the total welfare between consumer and producer surplus in order to analyze the re-distributive effects (between wholesalers and suppliers), that is the change in their share caused by the shift to the new competitive market structure.

[Table 7 here]

The total surplus is mainly held by wholesalers whose average share amounts around to 82%. Removing the suppliers' strategic behavior slightly increases the wholesalers' shares by a percentage ranging between the 0.7% and 1.7%; changes in consumers' surplus are even more marginal when we neutralize the oligopsonistic market power where the deltas settle around 0.33Compared to the average share held by consumers, producers' surplus undergoes major changes, decreasing by 5.5% in 2013 and by 2.56% in 2014; that is essentially caused by the greater elasticity of the supply curve. When we correct the bid prices taking into account the LS index, the suppliers' shares deeply decrease by 3.59% and 6.69%. On the other hand, when we eliminate the oligopsonistic market power, the welfare of producers increases by 1.06% and 1.64%.

Note that when we take into account the effects of purchasers' strategic behavior, the reduction on the consumers share is lower than the increase of the suppliers share, given that the supply curve is more elastic than the demand curve.

[Tables 8-9 here]

The analysis is broken down by quarters and peak-off-peak periods in Tables 8-9. Social welfare increases more during off-peak hours in both periods confirming the previous findings. The overall effect on the surplus shares (for both purchasers and suppliers) is the same than that on the total welfare: the shares of purchasers increase more during off-peak hours (by about 1.45%) while shares of suppliers decrease on average by 5.61%.

## 6. Conclusions

This paper provided an empirical measurement of the dead-weight loss of welfare in the Italian electricity market due to the strategic behavior of both suppliers and purchasers. The paper offered a counterfactual simulation of the competitive market solution, correcting the historical bids with a measure of the market power of main suppliers and purchasers, the LI. The simulation model we implemented recovers the competitive equilibrium taking into account the forward contracts and the presence of a competitive fringe, allowing to measure the deviation of the actual market equilibrium from the counterfactual competitive one.

Results highlight that the wholesale Italian electricity market recorded a welfare dead-weight loss in both the 2013 and the 2014. The deviation from competitive equilibrium appears to be more pronounced in clearing prices rather than exchange quantities: conterfactual competitive prices are on average the 3.29% lower than the recorded clearing prices, while divergence between historical and competitive quantities is about 0.77%.

The gap from the competitive equilibrium is essentially due to the oligopolistic behavior of strategic suppliers but results highlighted that even purchasers are able to hold some market power. The lower prices and the higher sales volumes derived in the simulated competitive framework would allow to retrieve the social welfare dead-weight loss, which is on average 0.46%. This latter loss is larger during off-peak hours when the ability of strategic players to deviate from the competitive bids is higher.

Removing market power essentially implied the purchasers to increase their share of welfare, which in the two years averagely increase by 0.92%. On the other hand, the supply side of market recorded larger loss since its yearly average share on the total welfare decreased by 4.03%.

In conclusion, despite recent achievements in the policy process aimed at spurring competition, increasing efficiency and reducing prices in the electricity market, these results highlight that there is still a deficit regarding the achievement of the ideal market conditions to maximize consumers' welfare. In this context policy makers must continue to strive for the benefits of the electricity market liberalization, by incorporating market mechanisms to mitigate or avoid market power. The non-regulated component of tariffs, that is the electricity price, is still at risk of being manipulated by the strategic players in the wholesale electricity market. We advocate that the completion of the electricity market liberalization will occur when this likelihood of manipulation is minimized or annihilated, thus rendering to the consumer an electricity price equal to its marginal cost.

## 7. Bibliography

Anielski M, Bushnell JB, Wolak FA. Measuring market inefficiencies in california's restructured wholesale electricity market. The American Economic Review 2002;92(5):1376–405.

Athey S, Haile PA. Empirical Models of Auctions. Working Paper 12126; National Bureau of Economic Research; 2006. URL: http://www.nber.org/papers/w12126. doi:10.3386/w12126.

Berk RA. A primer on robust regression. In: Fox J, (Hg.) JSL, editors. Modern Methods of Data Analysis. Newbury Park, CA: Sage; 1990. p. 292–324.

Bigerna S, Bollino C, Polinori P, et al. Market power and transmission congestion in the italian electricity market. Energy Journal 2016;37(2):133–54.

Bigerna S, Bollino CA. Measuring oligopsony market power in the italian electricity market: preliminary results. International Advances in Economic Research 2014;20(4):457–8.

Boffa F, Pingali V, Vannoni D. Increasing market interconnection: an analysis of the italian electricity spot market. International Journal of Industrial Organization 2010;28(3):311–22.

Bolle F. Supply function equilibria and the danger of tacit collusion: the case of spot markets for electricity. Energy Economics 1992;14(2):94–102.

Bolle F. Competition with supply and demand functions. Energy Economics 2001;23(3):253–77.

Borenstein S, Bushnell J, Wolak F. Diagnosing market power in California's restructured wholesale electricity market. Working Paper 7868; National Bureau of Economic Research; 2000. URL: http://www.nber.org/papers/w7868. doi:10.3386/w7868.

Borenstein S, Bushnell JB, Wolak FA. Measuring market inefficiencies in california's restructured wholesale electricity market. The American Economic Review 2002;92(5):1376–405. URL: http://www.jstor.org/stable/3083255.

Bosco B, Parisio L, Pelagatti M. Strategic bidding in vertically integrated power markets with an application to the italian electricity auctions. Energy Economics 2012;34(6):2046–57.

Cramton P. Competitive bidding behavior in uniform-price auction markets. In: System Sciences, 2004. Proceedings of the 37th Annual Hawaii International Conference on. IEEE; 2004. p. 1–11. doi:https://doi.org/10.1109/HICSS.2004.1265172.

Goodall C. M-estimators of location: An outline of the theory. volume 5. New York: Wiley, 1983.

Green RJ, Newbery DM. Competition in the british electricity spot market. Journal of Political Economy 1992;100(5):929–53.

Guerre E, Perrigne I, Vuong Q. Optimal nonparametric estimation of first-price auctions. Econometrica 2000;68(3):525–74.

Harvey S, Hogan W. Market power and market simulations. Technical Report; Center for Business and Government John F. Kennedy School of Government; Harvard University; 2002. URL: https://sites.hks.harvard.edu/hepg/Papers/Hogan_Harvey_Market_Power&Simulations_071602.pdf.

Holmberg P, Newbery D, Ralph D. Supply function equilibria: step functions and continuous representations. Journal of Economic Theory 2013;148(4):1509–51.

Hortacsu A, Puller SL. Understanding strategic bidding in multi-unit auctions: a case study of the texas electricity spot market. The RAND Journal of Economics 2008;39(1):86–114.

Joskow PL, Kohn E. A quantitative analysis of pricing behavior in california's wholesale electricity market during summer 2000. The Energy Journal 2002;23(4):1–35.

Klemperer PD, Meyer MA. Supply function equilibria in oligopoly under uncertainty. Econometrica: Journal of the Econometric Society 1989;57(6):1243–77.

Mansur ET. Measuring welfare in restructured electricity markets. The Review of Economics and Statistics 2008;90(2):369–86.

Newbery DM. Competition, contracts, and entry in the electricity spot market. The RAND Journal of Economics 1998;29(4):726–49.

Parisio L, Bosco B. Market power and the power market: multi-unit bidding and (in) efficiency in electricity auctions. International Tax and Public Finance 2003;10(4):377–401.

Reguant M. Complementary bidding mechanisms and startup costs in electricity markets. The Review of Economic Studies 2014;81(4):1708–42.

Sapio A, Spagnolo N. Price regimes in an energy island: tacit collusion vs. cost and network explanations. Energy Economics 2016;55:157–72.

Wilson R. Auctions of shares. The Quarterly Journal of Economics 1979;93(4):675–89.

Wolak FA. An empirical analysis of the impact of hedge contracts on bidding behavior in a competitive electricity market. International Economic Journal 2000;14(2):1–39.

Wolak FA. Measuring unilateral market power in wholesale electricity markets: the california market, 1998-2000. The American Economic Review 2003;93(2):425–30.

Wolfram CD. Measuring duopoly power in the british electricity spot market. American Economic Review 1999;89(4):805–26.

## 8. Appendix A. Robustness Analysis

This section tests the robustness of our analysis comparing the previous results to alternative estimation methods for beta coefficients and the demand and supply predictions.

The first estimation method we applied involves non-parametric local regression techniques where the supply and demand predictions are derived using the kernel weights leading to a much smoother regression function. The derived coefficients are the lowess estimates that minimize the weighted average least squared where the weights are the tricubic kernel weights downweghting large residuals. Compared to the traditional kernel regression estimator, the lowess estimator is more robust to outliers using a variable bandwidth. The graphs below (Figure A1-A8) depict the linear predictors and the lowess estimators for both demand and supply curves. The line plots refer to the OLS estimators, while the scatter plots refer to lowess estimators. Both kinds of predictions were performed for the old curves and for the new supply and demand functions adjusted by the Lerner indexes.

[Figure A1-A8 here]

Since the two samples are not independent the diagnostic procedure involves performing the Wilcoxon signed rank test, a paired difference test checking if the two population mean ranks of the repeated measurements on the single sample are the same.

The null hypothesis the linear prediction for the supply and demand curves, adjusted and not for the Lerner Index, do not show significant differences with the lowess predictions and they come from the same distribution. Under the null hypothesis assumes the two matched samples (the linear and the lowess predictions) arise from the same distribution and the difference between the pairs follows a symmetric non-canonical distribution around zero. As the sample size increases, the non-convetional distribution of the test statistic converges to the normal distribution with mean zero. Therefore, the test statistics have to show absolute values roughly smaller than 1,96 in order to not fall in the rejection region with a significance level of 5%. In both the years the test infers that in the roughly 90% of the hours the linear and the lowesss predictions are derived from the same distributions. We reported the main descriptive values for the Wilcoxon test statistics we computed for the 2013 and 2014 in Tables A1-A2.

[Tables A1-A2 here]

Second, we perform a robust regression using iteratively re-weighted least square, where the weight assigned to each observation depend on its residual (Berk, 1990; Goodall, 1983). [10]. This alternative estimation method instead, begins by fitting the regression and calculating Cook's distance and then excluding observations whose Distance are larger than 1. Thereafter the regression is performed iteratively. The iteration starts using the Huber weighting function until the convergence, then form that residual the iteration computes the estimator using the bi-weight function. The program uses both the Hubert and the bi-weights functions since the first ones has problem in dealing with outliers data, while the second ones may have multiple solutions or come short to convergence. After running the robust regression we compared them with our previous results. The derived estimates of demand and supply curves are then compared to the linear predictions using again the Wilcoxon signed rank test. Even for these estimations we depict the two different prediction curves. Again, the line plots refer to the OLS estimators, while the scatter plots refer to the re-weighted least square estimators. Both kinds of prediction were performed for the old curves and the new supply and demand functions adjusted by the Lerner indexes.
As before, the re-weighted prediction are the compared we the linear supply and demand curves (see Tables A3-A4). Conclusions do not change, the Wilcoxon

[10] We preferred the re-weighted regression rather than the traditional Bootstrap on the standard errors of the coefficient regressors since this procedure, although derives estimators with narrower confidence intervals, does not change the values of the coefficients estimate and it does not allow any comparison between different kinds of predictions but only efficiency judgements.

tests confirm that the linear and the re-weighted prediction source from the same distribution.

[Tables A3-A4 here]

## 9. Tables and Figures

Table 1: HH Index by zones and load periods.

| Absolute frequency | | |
|---|---|---|
| Zone | Peak | Offpeak |
| 2013 | | |
| CSUD | 3163.4 | 3740.67 |
| SUD | 3737.15 | 1725.76 |
| NORD | 1356.02 | 1213.12 |
| CNOR | 2926.76 | 2692.34 |
| SICI | 3612.43 | 3243.73 |
| SARD | 4294.9 | 3986.38 |
| 2014 | | |
| CSUD | 3708.86 | 4478.39 |
| SUD | 3095.11 | 1428.89 |
| NORD | 1471.25 | 1441.09 |
| CNOR | 2951.25 | 2799.29 |
| SICI | 2674.77 | 2590.52 |
| SARD | 4460.14 | 4162.41 |

Table 2: Market configurations (%) in the period 2004-2015.

| Year | Zone Division | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 2004 | 4.83 | 27.78 | 46.37 | 19.41 | 1.61 |
| 2005 | 23.03 | 47.77 | 25.81 | 3.34 | 0.05 |
| 2006 | 19.05 | 40.66 | 29.89 | 9.25 | 1.15 |
| 2007 | 22.53 | 41.71 | 29.52 | 6.06 | 0.17 |
| 2008 | 19.32 | 44.29 | 29.52 | 6.23 | 0.65 |
| 2009 | 15.16 | 35.62 | 37.5 | 11.27 | 0.46 |
| 2010 | 17.69 | 37.77 | 32.45 | 11.38 | 0.7 |
| 2011 | 15.49 | 45.89 | 31.63 | 6.56 | 0.42 |
| 2012 | 9.82 | 59.82 | 27.21 | 2.96 | 0.18 |
| 2013 | 6.34 | 64.12 | 25.23 | 4.13 | 0.18 |
| 2014 | 8.17 | 58.77 | 29.62 | 3.41 | 0.02 |
| 2015 | 11.16 | 59.6 | 24.67 | 4.32 | 0.25 |
| Average | 14.58 | 47.39 | 30.46 | 7.11 | 0.46 |

Table 3: Number of hours used for the empirical analysis.

| Year | I Quarter | II Quarter | III Quarter | IV Quarter | Tot |
|---|---|---|---|---|---|
| 2013 | 1165 | 1462 | 1680 | 1430 | 5737 |
| | (53.93) | (66.94) | (76.08) | (64.76) | (0.65) |
| 2014 | 1513 | 1224 | 1274 | 1495 | 5506 |
| | (70.05) | (56.04) | (57.7) | (67.71) | (0.63) |

Table 4: Current clearing prices and quantities and their estimated variations: years 2013-2014.

| | Current clearing price | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
|---|---|---|---|---|
| 2013 | 63.62 | -5.88 | 1.49 | -4.58 |
| 2014 | 52.51 | -3.16 | 1.17 | -2.01 |
| Average | 58.06 | -4.52 | 1.33 | -3.29 |
| | Current clearing quantity | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
| 2013 | 31863 | 0.59 | 0.37 | 0.96 |
| 2014 | 30945 | 0.25 | 0.33 | 0.59 |
| Average | 31404 | 0.42 | 0.35 | 0.77 |

Table 5: Current clearing prices and quantities and their estimated variations by quarters and load periods: years 2013.

| 2013 | | | | | |
|---|---|---|---|---|---|
| | | Current clearing price | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
| I Quarter | Peak | 69.21 | -5.34 | 1.5 | -3.77 |
| | Off-Peak | 63.98 | -5.8 | 1.83 | -4.2 |
| II Quarter | Peak | 57.09 | -7.69 | 3.73 | -5.06 |
| | Off-Peak | 56.74 | -8.41 | 2.54 | -6.02 |
| III Quarter | Peak | 69.45 | -5.65 | 0.28 | -5.38 |
| | Off-Peak | 64.39 | -5.18 | 0.4 | -4.8 |
| IV Quarter | Peak | 64.88 | -4.31 | 1.15 | -3.2 |
| | Off-Peak | 63.82 | -4.62 | 0.96 | -3.7 |
| Average | Peak | 65.16 | -5.75 | 1.67 | -4.35 |
| | Off-Peak | 62.23 | -6 | 1.43 | -4.68 |
| | | Current clearing quantity | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
| I Quarter | Peak | 34092 | 0.62 | 0.56 | 1.18 |
| | Off-Peak | 33053 | 0.7 | 0.57 | 1.27 |
| II Quarter | Peak | 29727 | 0.91 | 0.59 | 1.5 |
| | Off-Peak | 31026 | 0.98 | 0.49 | 1.48 |
| III Quarter | Peak | 31632 | 0.27 | 0.1 | 0.37 |
| | Off-Peak | 33457 | 0.31 | 0.14 | 0.46 |
| IV Quarter | Peak | 31125 | 0.5 | 0.34 | 0.84 |
| | Off-Peak | 31070 | 0.52 | 0.33 | 0.85 |
| Average | Peak | 31644 | 0.58 | 0.4 | 0.97 |
| | Off-Peak | 32151 | 0.63 | 0.38 | 1.02 |

Table 6: Current clearing prices and quantities and their estimated variations by quarters and load periods: years 2014.

| | | 2014 | | | |
|---|---|---|---|---|---|
| | | Current clearing price | $\Delta_1$% | $\Delta_2$% | $\Delta_{Tot}$% |
| I Quarter | Peak | 57.57 | -4.57 | 1.75 | -2.88 |
| | Off-Peak | 55.57 | -5.08 | 1.92 | -3.14 |
| II Quarter | Peak | 46.72 | -2.69 | 0.86 | -1.85 |
| | Off-Peak | 47.23 | -2.98 | 0.97 | -1.99 |
| III Quarter | Peak | 47.01 | -2.36 | 1.11 | -1.28 |
| | Off-Peak | 51.7 | -3.23 | 0.84 | -2.43 |
| IV Quarter | Peak | 57.17 | -2.18 | 0.63 | -1.56 |
| | Off-Peak | 54.77 | -1.93 | 1.05 | -0.96 |
| Tot | Peak | 52.12 | -2.95 | 1.09 | -1.89 |
| | Off-Peak | 52.32 | -3.31 | 1.2 | -2.13 |
| | | Current clearing quantity | $\Delta_1$% | $\Delta_2$% | $\Delta_{Tot}$% |
| I Quarter | Peak | 31943 | 0.34 | 0.45 | 0.79 |
| | Off-Peak | 32282 | 0.42 | 0.51 | 0.93 |
| II Quarter | Peak | 28875 | 0.2 | 0.2 | 0.41 |
| | Off-Peak | 30353 | 0.25 | 0.24 | 0.5 |
| III Quarter | Peak | 31015 | 0.19 | 0.42 | 0.61 |
| | Off-Peak | 32258 | 0.24 | 0.32 | 0.56 |
| IV Quarter | Peak | 30754 | 0.19 | 0.21 | 0.4 |
| | Off-Peak | 29761 | 0.17 | 0.27 | 0.44 |
| Tot | Peak | 30647 | 0.23 | 0.32 | 0.55 |
| | Off-Peak | 31163 | 0.27 | 0.34 | 0.61 |

Table 7: Current welfare, consumers' and producers' surplus and their estimated variations: years 2013-2014.

| | Current social welfare | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
|---|---|---|---|---|
| 2013 | 8871643 | 0.19 | 0.36 | 0.55 |
| 2014 | 8530748 | 0.07 | 0.31 | 0.39 |
| Average | 8701195 | 0.13 | 0.33 | 0.46 |
| | Current consumer surplus | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
| 2013 | 79.88 | 1.74 | -0.37 | 1.36 |
| 2014 | 82.84 | 0.73 | -0.26 | 0.47 |
| Average | 81.36 | 1.23 | -0.31 | 0.92 |
| | Current Producer surplus | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
| 2013 | 20.12 | -6.69 | 1.64 | -5.5 |
| 2014 | 17.16 | -3.59 | 1.06 | -2.56 |
| Average | 18.64 | -5.14 | 1.35 | -4.03 |

Table 8: Current welfare, consumers' and producers' surplus and their estimated variations by quarters and load periods: years 2013.

| | | 2013 | | | |
|---|---|---|---|---|---|
| | | Current social welfare | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
| I Quarter | Peak | 9.68 | 0.17 | 0.49 | 0.66 |
| | Off-Peak | 8.61 | 0.19 | 0.53 | 0.72 |
| II Quarter | Peak | 6.62 | 0.19 | 0.57 | 0.76 |
| | Off-Peak | 7.11 | 0.22 | 0.52 | 0.74 |
| III Quarter | Peak | 10.63 | 0.16 | 0.08 | 0.24 |
| | Off-Peak | 10.69 | 0.17 | 0.11 | 0.28 |
| IV Quarter | Peak | 8.46 | 0.2 | 0.38 | 0.58 |
| | Off-Peak | 8.67 | 0.22 | 0.32 | 0.55 |
| Average | Peak | 8.85 | 0.18 | 0.38 | 0.56 |
| | Off-Peak | 8.77 | 0.2 | 0.37 | 0.57 |
| | | Current consumer surplus | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
| I Quarter | Peak | 79.95 | 1.4 | -0.41 | 0.98 |
| | Off-Peak | 79.1 | 1.58 | -0.42 | 1.14 |
| II Quarter | Peak | 75.19 | 2.8 | -0.78 | 2 |
| | Off-Peak | 75.82 | 3.28 | -0.66 | 2.61 |
| III Quarter | Peak | 83.27 | 1.26 | -0.06 | 1.2 |
| | Off-Peak | 83.81 | 1.14 | -0.08 | 1.06 |
| IV Quarter | Peak | 79.61 | 1.23 | -0.4 | 0.82 |
| | Off-Peak | 80.86 | 1.3 | -0.3 | 1 |
| Average | Peak | 79.51 | 1.67 | -0.41 | 1.25 |
| | Off-Peak | 79.9 | 1.83 | -0.37 | 1.45 |
| | | Current producer surplus | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
| I Quarter | Peak | 20.05 | -6.22 | 1.52 | -4.71 |
| | Off-Peak | 20.9 | -6.64 | 3.3 | -5.12 |
| II Quarter | Peak | 24.81 | -8.31 | 4.1 | -5.93 |
| | Off-Peak | 24.18 | -9.12 | 2.36 | -6.96 |

| | | | | | |
|---|---|---|---|---|---|
| III Quarter | Peak | 16.73 | -6.55 | 0.26 | -6.31 |
| | Off-Peak | 16.19 | -6.06 | 0.38 | -5.7 |
| IV Quarter | Peak | 20.39 | -5.07 | 1.01 | -4.11 |
| | Off-Peak | 19.14 | -5.48 | 0.87 | -4.65 |
| Average | Peak | 20.5 | -6.54 | 1.72 | -5.27 |
| | Off-Peak | 20.1 | -6.83 | 1.73 | -5.61 |

Table 9: Current welfare, consumers' and producers' surplus and their estimated variations by quarters and load periods: years 2014.

| | | 2014 | | | |
|---|---|---|---|---|---|
| | | Current social welfare | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
| I Quarter | Peak | 9.09 | 0.13 | 0.43 | 0.56 |
| | Off-Peak | 8.78 | 0.14 | 0.51 | 0.65 |
| II Quarter | Peak | 7.95 | 0.04 | 0.21 | 0.25 |
| | Off-Peak | 8.06 | 0.04 | 0.25 | 0.3 |
| III Quarter | Peak | 8.12 | 0.05 | 0.27 | 0.32 |
| | Off-Peak | 8.98 | 0.08 | 0.24 | 0.32 |
| IV Quarter | Peak | 9.09 | 0.06 | 0.21 | 0.27 |
| | Off-Peak | 8.12 | 0.05 | 0.29 | 0.34 |
| Average | Peak | 8.57 | 0.07 | 0.28 | 0.35 |
| | Off-Peak | 8.48 | 0.08 | 0.32 | 0.4 |
| | | Current consumer surplus | $\Delta_1\%$ | $\Delta_2\%$ | $\Delta_{Tot}\%$ |
| I Quarter | Peak | 81.8 | 1.09 | -0.39 | 0.7 |
| | Off-Peak | 81.12 | 1.24 | -0.45 | 0.78 |
| II Quarter | Peak | 83.74 | 0.6 | -0.19 | 0.4 |
| | Off-Peak | 82.64 | 0.67 | -0.23 | 0.44 |
| III Quarter | Peak | 85.59 | 0.49 | -0.16 | 0.33 |
| | Off-Peak | 84.75 | 0.69 | -0.14 | 0.55 |
| IV Quarter | Peak | 82.82 | 0.51 | -0.16 | 0.34 |

| | | | | | |
|---|---|---|---|---|---|
| | Off-Peak | 81.3 | 0.48 | -0.26 | 0.22 |
| Average | Peak | 83.49 | 0.67 | -0.23 | 0.44 |
| | Off-Peak | 82.45 | 0.77 | -0.27 | 0.5 |
| | | Current producer surplus | $\Delta_1$% | $\Delta_2$% | $\Delta_{Tot}$% |
| I Quarter | Peak | 18.2 | -5.21 | 1.58 | -3.7 |
| | Off-Peak | 18.88 | -5.75 | 1.7 | -4.01 |
| II Quarter | Peak | 16.26 | -3.07 | 0.77 | -2.32 |
| | Off-Peak | 17.36 | -3.33 | 0.86 | -2.46 |
| III Quarter | Peak | 14.41 | -2.8 | 1.11 | -1.73 |
| | Off-Peak | 15.25 | -3.72 | 0.83 | -2.95 |
| IV Quarter | Peak | 17.18 | -2.45 | 0.55 | -1.91 |
| | Off-Peak | 18.7 | -2.16 | 0.92 | -1.31 |
| Average | Peak | 16.51 | -3.38 | 1 | -2.42 |
| | Off-Peak | 17.55 | -3.74 | 1.08 | -2.68 |

Table A1: Wilcoxon Test Statistic Linear vs Lowess Predictions. Summary values; 2013.

| Statistics | Supply price | Demand price | Adj. supply price | Adj. demand price |
|---|---|---|---|---|
| 1% | -3.36 | -4.52 | -1.74 | -4.00 |
| 5% | -2.02 | -3.07 | -1.42 | -3.19 |
| 10% | -1.56 | -2.79 | -1.27 | -2.50 |
| 25% | -1.07 | -2.01 | -0.68 | -1.82 |
| 50% | -0.22 | -1.25 | 0.15 | -0.86 |
| 75% | 0.73 | -0.4 | 1.27 | 0.56 |
| 90% | 1.7 | 0.61 | 1.90 | 1.21 |
| 95% | 2.12 | 0.99 | 2.12 | 1.80 |
| 99% | 2.41 | 1.92 | 2.53 | 2.22 |
| Mean | -0.11 | -1.17 | 0.29 | -0.71 |
| Std. Dev. | 1.28 | 1.26 | 1.15 | 1.51 |
| Variance | 1.64 | 1.59 | 1.34 | 2.28 |
| Skewness | 0.09 | 0.15 | 0.09 | -0.0 |
| Kurtosis | 2.68 | -4.5 | 1.93 | 2.30 |

Table A2: Wilcoxon Test Statistic Linear vs Lowess Predictions. Summary values; 2014.

| Statistics | Supply price | Demand price | Adj. supply price | Adj. demand price |
|---|---|---|---|---|
| 1% | -2.89 | -3.79 | -2.27 | -3.40 |
| 5% | -1.95 | -3.39 | -1.63 | -2.86 |
| 10% | -1.54 | -2.94 | -1.18 | -2.42 |
| 25% | -0.89 | -2.34 | -0.62 | -1.85 |
| 50% | 0.02 | -1.46 | 0.24 | -1.14 |
| 75% | 1.17 | -0.38 | 0.96 | -0.12 |
| 90% | 1.76 | 0.62 | 1.54 | 1.13 |
| 95% | 2.01 | 1.20 | 1.86 | 1.68 |
| 99% | 3.08 | 2.10 | 2.88 | 2.17 |
| Mean | 0.09 | -1.30 | 0.2 | -0.9 |
| Std. Dev. | 1.28 | 1.37 | 1.08 | 1.32 |
| Variance | 1.64 | 1.88 | 1.18 | 1.74 |
| Skewness | 0.00 | 0.50 | -0.0 | 0.50 |
| Kurtosis | 2.33 | 2.85 | 2.68 | 2.71 |

Table A3: Wilcoxon Test Statistic: Linear vs Robust Predictions. Summary values; 2013.

| Statistics | Supply price | Demand price | Adj. supply price | Adj. demand price |
|---|---|---|---|---|
| 1% | -2.34 | -2.34 | -2.02 | -2.21 |
| 5% | -1.34 | -1.34 | -1.60 | -1.46 |
| 10% | -1.12 | -1.12 | -1.34 | -1.15 |
| 25% | -0.44 | -0.44 | -0.67 | -0.44 |
| 50% | 0.105 | 0.105 | 0 | 0.04 |
| 75% | 1 | 1 | 0.73 | 0.98 |
| 90% | 1.50 | 1.50 | 1.34 | 1.47 |
| 95% | 1.89 | 1.89 | 1.60 | 2.02 |
| 99% | 3.93 | 3.93 | 2.19 | 4.54 |
| Mean | 0.27 | 0.27 | 0.00 | 0.21 |
| Std. Dev. | 1.10 | 1.10 | 1.01 | 1.11 |
| Variance | 1.22 | 1.22 | 1.03 | 1.25 |
| Skewness | 0.52 | 0.52 | 0.29 | 0.62 |
| Kurtosis | 4.12 | 4.12 | 3.43 | 4.68 |

Table A4: Wilcoxon Test Statistic: Linear vs Robust Predictions. Summary values; 2014.

| Statistics | Supply price | Demand price | Adj. supply price | Adj. demand price |
|---|---|---|---|---|
| 1% | -2.80 | -2.43 | -2.50 | -2.11 |
| 5% | -1.77 | -1.44 | -1.60 | -1.60 |
| 10% | -1.30 | -1.15 | -1.34 | -1.34 |
| 25% | -0.67 | -0.44 | -0.67 | -0.52 |
| 50% | -0.00 | 0.40 | 0.15 | 0.39 |
| 75% | 0.727 | 1.24 | 1 | 1.34 |
| 90% | 1.34 | 2.20 | 1.47 | 2.02 |
| 95% | 1.78 | 3.85 | 1.82 | 3.06 |
| 99% | 3.21 | 6.69 | 3.09 | 5.38 |
| Mean | 0.00 | 0.56 | 0.14 | 0.44 |
| Std. Dev. | 1.11 | 1.66 | 1.13 | 1.47 |
| Variance | 1.23 | 2.76 | 1.29 | 2.16 |
| Skewness | 0.05 | 1.30 | 0.08 | 0.90 |
| Kurtosis | 3.54 | 5.88 | 2.85 | 4.72 |

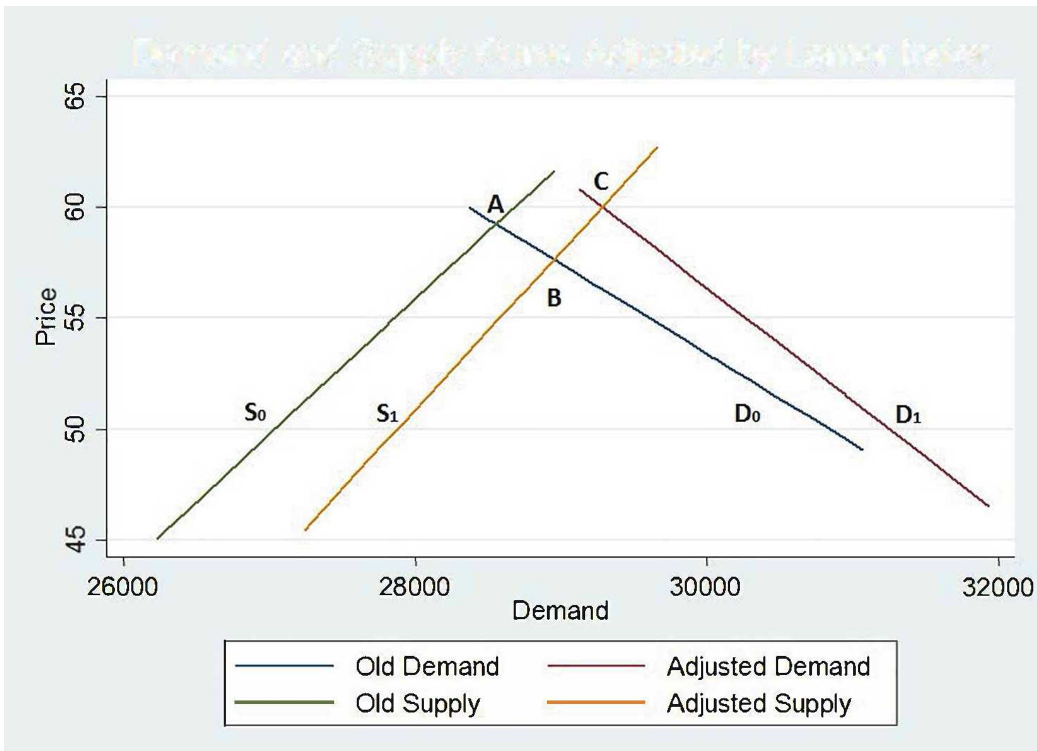


Figure 1: Simulation model of competitive equilibrium.

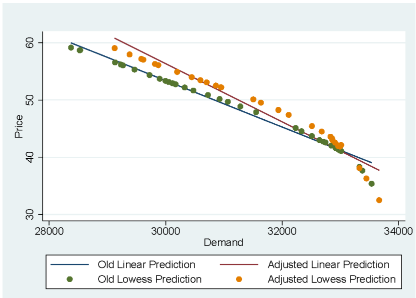


Figure A1: Lowess Demand Linear Prediction Off Peak Hour 2013

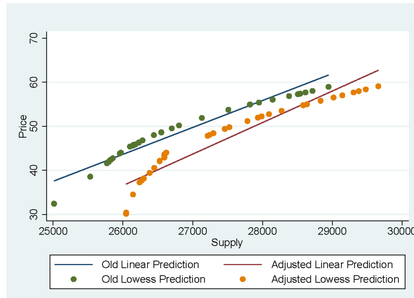


Figure A2: Lowess Linear Supply Prediction Off Peak Hour 2013

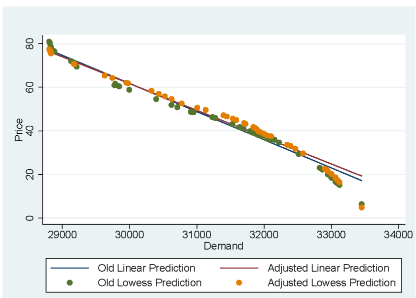


Figure A3: Lowess Linear Demand Prediction Peak Hour 2013

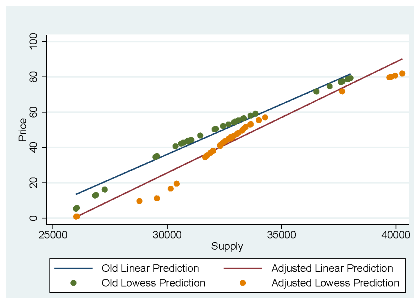


Figure A4: Lowess Linear Supply Prediction Peak Hours 2013

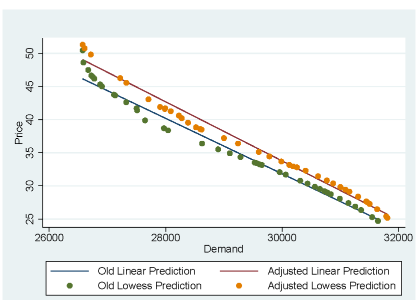


Figure A5: Lowess Linear Demand Prediction Off Peak Hour 2014

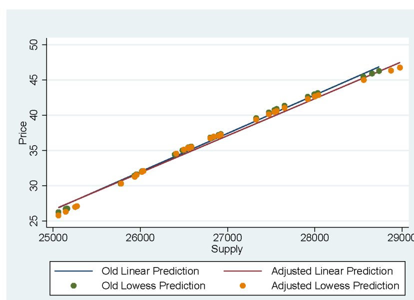


Figure A6: Lowess Linear Supply Prediction Off Peak Hour 2014

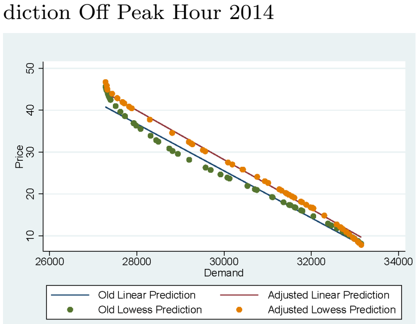


Figure A7: Lowess Linear Demand Prediction Peak Hour 2014

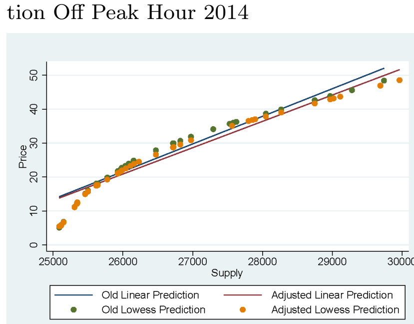


Figure A8: Lowess Linear Supply Prediction Peak Hour 2014