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EPRG Working Paper 1930

Cambridge Working Paper in Economics 1975

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Keywords Electricity Wholesale Market, Market Power, Bidding Strategy, Synthetic Supply

JEL Classification L94

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Publication July 2019

Assessing Market Power in the Italian Electricity Market: A synthetic supply approach

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Abstract

The aim of this article is to investigate the effects of the bidding strategies of leading firms on market equilibria. The analysis focuses on the Italian wholesale electricity market from 2015 to 2018. The purpose is to assess if the observed market equilibria are the results of a competitive setting or if more competitive equilibria could have occurred. We use the methodology of synthetic supply proposed by Ciarreta et al. (2010a). This way, a new set of synthetic prices and quantities is computed. The comparison between the actual and synthetic prices allows us to assess the effects of market power on the actual equilibria. Results suggest that whilst there is a significant impact on prices, quantities seem not to be affected, due to the inelastic demand. Moreover, our findings suggest that the main impacts occurred during 2017 especially during those months where above average heating and cooling were required.

1 Introduction

The Italian electricity market was subject to several changes over the past two decades. Indeed, after liberalization, the market experienced different settings such as the evolution of the bidding zones and of the intraday markets, the improvement of market coupling, the massive introduction of RES and the reduction of market power asymmetries.

It is important to keep in mind that the Italian electricity market is characterized by a large share of generation based on coal and gas and the absence of nuclear generation. However, what is remarkable is the structural change that renewable sources produced in the last years, which affected the bidding behaviors of fossil fuel plants. Indeed, according to Bigerna et al. (2016) the total electricity consumption, generated by RES, drastically increased shifting from 3-4% to 30% between 2010 and 2013. RES, due to their zero marginal costs, tended to significantly affect prices by lowering them. In particular, the sizeable generation produced by solar panels reduced the profit margins of several power plants during the day hours. However, during the night, when the production from solar panels fell, the owners of fossil fuel plants exercised their market power again in order to compensate the losses sustained during the day hours.

Despite the fact that the issue related to market power asymmetries has been substantially tackled in these years, uncompetitive behaviors seem to persist. Several examples can be highlighted and quoted. Probably, the most interesting case, occurred in the first months of 2016. Some owners of fossil fuels power plants were capable of drastically increasing their revenues by applying bidding strategies intended to deliberately unbalance the market to achieve extremely high profits in the ancillary service market. This case will be discussed in the literature review. In addition, the exercise of market power may increase when the imported supply drops or during the maintenance of transmission power cables. Therefore, it is extremely relevant to analyse the operators' behaviors and study their bidding strategies as they keep changing and evolving over time.

This study aims to provide further evidence on the market monitoring field by applying the technique of synthetic supply proposed by Ciarreta et al. (2010a). In particular, the Italian Day-Ahead market is considered as a case study and its hourly equilibria are analysed. The goal of this paper is to show if the actual equilibria are the result of a competitive setting or if more competitive equilibria might have been possible. Moreover, an estimate of Consumer Surplus Loss will be computed and an alternative version of Lerner Index will be provided. Our findings will be discussed with the aim of achieving a broader and wider understanding of the Italian electricity market.

2 Literature Review

Market manipulation has been widely discussed in recent years. This topic, due to its complexity and vastness, involves different disciplines. Indeed, in order to have a good understanding of the definition of market manipulation and of the principal techniques for its detection, it is necessary to have a sufficient degree of knowledge of several arguments. The study of this subject requires: a deep understanding of the structure of the market and of its dynamics and history; an advanced knowledge of economics and statistics; and a sufficient but necessary overview of law and electrical engineering. For this reason, several approaches have been proposed for analyzing market manipulation. Each approach is characterized by the weights that its authors give to these different disciplines. Pinczynski and Kasperowicz (2016) and Prabhakar Karthikeyan et al. (2013) offer two reviews about the different approaches and techniques that have been adopted over these decades.

In this section the main arguments discussed will be microeconomics and law. First it is important to define what is considered market manipulation from a legal point of view. REMIT (Regulation of Energy Market Integrity and Transparency) and its guidance proposed by ACER (Agency for the Cooperation of Energy Regulators) clarify the legal steps required for the identification of market manipulation. Many articles were published on this topic. Feltkamp (2013) proposes a deep analysis of REMIT and gives a detailed interpretation of this regulation. Harris and Ledgerwood (2012) present a concise but complete overview of REMIT. According to these authors, REMIT and the guidance published by ACER do not shed enough light on the concept of market manipulation. In fact, "these definitions were too broad to be easily understood and applied"[1]. For this reason, these authors suggested an alternative point of view which indicated the legal steps that should be required for the identification of a market manipulation. It is important to highlight that a legal interpretation of empirical results is necessary. In fact, in order to claim whether market manipulation occurred or not, it is essential to understand if the observed strategic behavior identification can be considered a market manipulation or only an uncompetitive behavior. Trigger, Target and Nexus are a good starting point for the legal interpretation of results (see Harris and Ledgerwood (2012), page 3). Once a general legal overview is in place it is possible to proceed

[1]Harris and Ledgerwood (2012), page 1.

with the assessment of market power.

In the literature, there are many articles that discuss how firms may exercise their market power. It is possible to analyse this topic from several perspectives by applying different techniques. For example, Bosco et al. (2013) analysed the bidding strategy of Enel Produzione S.p.A. by studying its profit functions. This approach allowed them to understand when Enel Produzione S.p.A. was exerting its pivotal position. Wolak (2003) studied the market power of five leading operators in California. In this paper, the estimates of their Lerner Indexes are provided. As the marginal costs are unknown, the author proposes to analyse these measures through the estimation of the elasticity of every hourly residual demand faced by each of these companies. By contrast, it is possible to estimate a Lerner Index for operator i by estimating its marginal costs. Ciarreta and Espinosa (2010a) proposed an alternative version of the Lerner Index based on synthetic prices. Bosco et al. (2012) estimated the marginal cost functions for some of the main Italian leading operators and provided further evidence of their Lerner Indexes.

Furthermore, it is essential to bear in mind that leading operators might exploit their market power jointly. A joint bidding strategy could be undertaken by an illegal cartel or, more simply, by tacit collusion. However, from an empirical point of view, it is extremely difficult to test whether collusion occurred or not and it is almost impossible to prove if it was intentional (the so called *"probatio diabolica"*). Macatangay (2003) investigated whether tacit collusion occurred in the wholesale electricity market of England and Wales at the end of the 90s. The firms suspected of this misbehavior were National Power and PowerGen. The bidding strategies of the operators were analysed. In particular the empirical analysis was run in two stages. In the first step, the author tested whether the bidding strategies of National Power and PowerGen differed from the others. In the second one, the existence of inter-dependence and co-ordination of the the leading operators' bidding strategies was investigated. However, despite the intriguing results, the author states that it is not possible to claim if tacit collusion occurred. Sweeting (2007) further investigates this case claiming that "their behavior was consistent with tacit collusion"[2].

Market splitting and renewables constitute further key elements for a in-depth analysis of competition. Bigerna et al. (2016) take into account market splitting in the computation of the Lerner Index, in order to have a more accurate estimate of market power. Indeed, the zonal pricing system may be used strategically by some operators. Furthermore, these

[2]Sweeting (2007), page 654.

authors showed how the bidding behaviors of fossil fuels plants changed after the massive introduction of RES. In particular, it seems that solar panels caused a fall in daytime prices decreasing the relevance of combined cycle gas plants. On the contrary, findings show that during the night the owners of combined cycle gas plants exercised their market power more often. Ciarreta et al. (2017) analysed the effects of RES on fossil fuels plants for the Spanish electricity market. Their findings show that the massive introduction of RES in the market affected the bidding behaviors of fossil fuel plants but only in the short run.

The majority of the available literature focuses on the day-ahead market. Most of the time, intra-day and ancillary service markets are not matters of discussion. However, for a wide and deep analysis of competition in the electricity market it is important to always keep in mind that wholesale electricity market constitutes only the "tip of the iceberg". In 2016, an interesting and complete investigation was carried out by Luigi Gabriele, Rete Italia Consumatori[3]. The analysis reported in this document shows how, in the first semester of 2016, some fossil fuel plants were capable to achieve extremely high revenues, in the ancillary service market, subsequent to strategic behaviors in day-ahead and intraday markets. The Italian Regulatory Authority for Energy (ARERA)[4] stated that anomalous behaviours occurred during these months. In particular, some companies implemented some strategies in order to achieve extra profit in the ancillary service market, namely electricity withdrawal or overbidding. The aim was to unbalance the regular dynamics of the markets in order for their plants to be necessary in the ancillary service market, where prices were way higher than in wholesale and intraday markets.

3 Market Structure

Italian electricity market is divided in six macro areas: North, Center North, Center South, South, Sicily and Sardinia (See Figure 1). These zones are connected to each other and with other countries (France, Switzerland, Austria, Slovenia, Greece and Malta) via transmission power cables.

The Italian electricity market is mainly composed by Spot Electricity Market and Forward Electricity Market. The analysis proposed in this chapter focuses only on the Day-Ahead Market (*"Mercato del Giorno Prima"*) which is a component of the Spot Electricity Market.

[3]The report is available at the following link

[4]ARERA's reports are available in the references.

The other main components are: the Intra-Day Market and the Ancillary Service Market.

Typically the market starts with the Day-Ahead Market's auction and an equilibrium is established. After that, Intra-day markets' auctions occur and in every auction an equilibrium is achieved. Both Day-Ahead Market's auction and Intra-Day Markets' ones are uniform price auctions. The final market is the Ancillary Service Market, which consists of several sessions. This is a "pay-as-bid" market. At the end of this procedure the market is balanced.

Figure 1: Market Splitting vs No Market Splitting (Zones)[a]

(a) 12/01/2017 02:00 am (b) 12/01/2017 05:00 pm

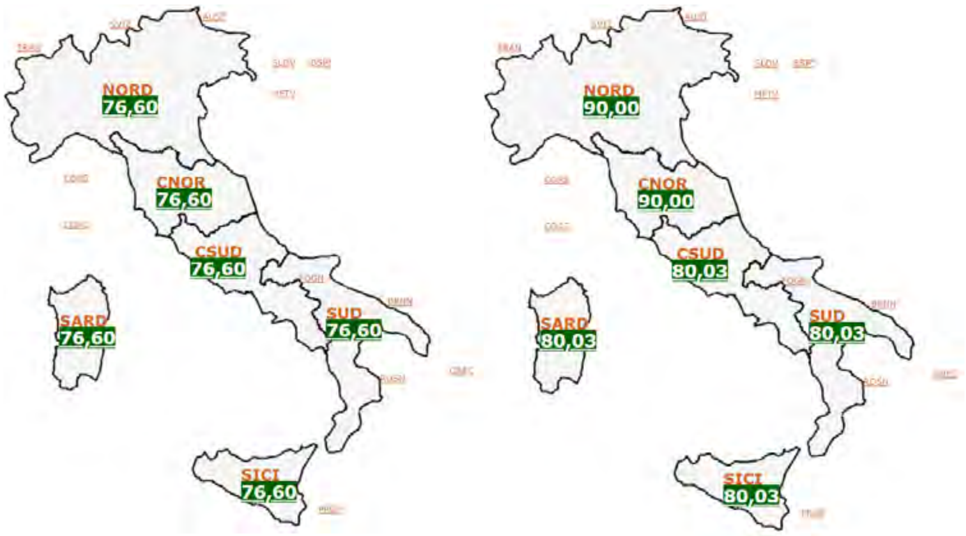


Fig (a) shows a case of no market splitting where all the zonal prices are the same.

Fig (b) shows a case where market splitting occurs: zonal prices are not equal.

Source: Gestore dei Mercati Energetici S.p.A.

[a]Here follows the list of the zones (in bold the currently active zones):

* Six geographical zones: ***NORD***, ***CNOR***, ***CSUD***, ***SUD***, ***SICI***, ***SARD***.

* Five poles of limited production: *MFTV*, ***ROSN***, *FOGN*, *BRNN*, *PRGP*.

* Eight foreign virtual zones: ***FRAN***, ***SVIZ***, ***AUST***, ***SLOV***, ***CORS***, ***COAC***, ***GREC***, ***MALT***.

* Three foreign virtual zones for market coupling: ***BSP***,***XFRA***, ***XAUS***.

Day-Ahead Market

Day-Ahead Market is structured as a uniform price hourly auction. Each auction opens 9 days before the target hour and it closes one day before. During this time lapse, operators can submit orders. Each order is a pair containing a price and a quantity. Buyers submit bids whereas sellers submit offers. Each supplier can submit a maximum of four offers from every power plant they own. Therefore, each offer is associated with a specific power plant. The Independent System Operator (ISO) receives and registers these bids/offers. In the first instance, it "translates" the bids (submitted by buyers) at zero price. Indeed, these bids are intended to be "at any price" and the price is converted from 0 € to 3000 € (maximum price). Once this procedure has been accomplished, the ISO proceeds with the computation of the demand and supply curves. These curves are computed as the cumulative sum of all the accepted/rejected orders. In particular, for demand, bids are ordered with a decreasing price criterion whereas, for supply, offers are ordered with an increasing price criterion (more precisely they are ordered through the "Merit Order" condition but this criterion will not be discussed here). Therefore, at the end of this procedure there will be two step curves for each hour. The intersection point between the two curves is the hourly equilibrium. It may happen that the two step functions intersect not in a point but rather in a segment. This segment can be vertical or horizontal. The former indicates a situation where there is price indeterminacy whereas the latter indicates quantity indeterminacy. In the first case, the equilibrium is set with the mid-price rule: the middle point of the intersection segment is chosen. In the second case, the welfare is maximized if the equilibrium is set when the quantity is maximized: the far right point of the segment is chosen. This equilibrium, is the unconstrained hourly equilibrium that does not take into account market congestion. In other words, unconstrained equilibrium assumes unlimited available transmission capacity (ATC)[5]. It may happen that, after the national auction, a zone bought more electricity than the production system of that zone sold. Thus, it is possible to send into that zone a certain amount of electricity. If this amount satisfies the demand, market splitting does not occur (See Figure 1(a) and 2(a)). On the contrary, if this amount is not enough and the transmission power cable is not able to carry more electricity, market splitting occurs. If market splitting occurs, two or more zonal auctions are automatically created and new equilibria are computed. This procedure is repeated until transmission power constraints are

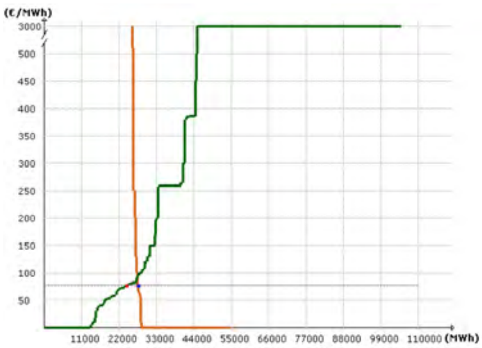
[5]Italian electricity markets is characterized by more than one zone. Therefore, more than one zonal price may occur.

not violated any more. The results of this procedure are different zonal prices as results of zonal auctions (See Figures 1(b), 2(b) and 2(c)). At the end sellers will sell the electricity at the zonal price whereas the buyer will buy the electricity according to PUN (*"Prezzo Unico Nazionale"*) which is the final national price computed as the weighted average of zonal prices. Foreign buyers pay the zonal price.

Figure 2: Market Splitting vs No Market Splitting (Curves)[a]

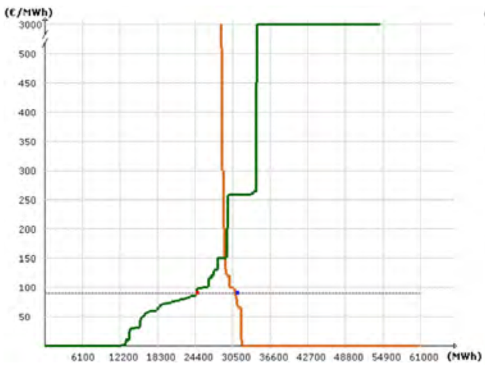
(a) 12/01/2017 02:00 am

All Zones



(b) 12/01/2017 05:00 pm

CNOR, NORD, AUST, CORS, FRAN, MFTV, SLOV, SVIZ, BSP.



(c) 12/01/2017 05:00 pm

CSUD, SARD, SICI, SUD, COAC, BRNN, FOGN, GREC, PRGP, ROSN, MALT.

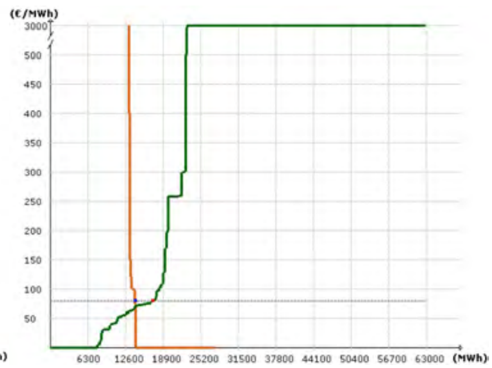


Fig (a) shows a case of no market splitting where only one auction occurs.

Fig (b) and Fig (c) show a case where market splitting occurs: more than one auction occurs.

Source: Gestore dei Mercati Energetici S.p.A.

[a]The red dot indicates the accepted offer quantitiy (supply) whereas the blue one indicates the accepted bid quantity (demand). The dotted line indicates the hourly zonal market clearing price. The difference between the two quantities depends on the electricity flows and market coupling. For example, in 2(a) the price is 76.60 €/MWh the accepted bid quantity is 27,663 MWh, the accepted offer quantity is 24,236 MWh and the total quantity sold by XFRA and XAUS is 3,427 MWh.

4 Data

Two sources compose the data set: Independent System Operator and REF-E, an Italian consulting company operating in the energy sector. In order to present the structure of the data in the clearest way, they are explained separately here below.

4.1 Independent System Operator

The analysis focuses on the day-ahead market, the so called *"Mercato del Giorno Prima" (MGP)*. The following information is available on the website of the Italian Independent System Operator (*"Gestore dei Mercati Energetici S.p.A."*):

1. Public domain bids/offers data
2. Market coupling data
3. Day-ahead market unconstrained prices.

4.1.1 Public domain bids/offers data

All the bidding schedules of the operators are registered in the public domain bids/offers data. The analysis has been carried out using four years of data: from March[6] 2015 to December 2018. Each annual data set contains twenty columns and approximately 25 million rows.

The main variables used for the data analysis are: quantity offered (adjusted), price, purpose (bid/offer), status (accepted and rejected; incomplete bids/offers are discarded from the sample), operator's name, power plant's name and hour. Bilateral contracts are included in the bidding schedule as they must be taken into account for the computation of the equilibrium point.

4.1.2 Market coupling data

From February 2015, there are three market coupling "zones": Slovenia Market Coupling, Austria Market Coupling and France Market Coupling. The quantities that every hour flow across the border (in-going/outgoing) affect the hourly equilibria.

[6]Before March 2015 (precisely the 24th of February) there was another algorithm for the computation of NAT. Therefore, it is not possible, with the R code developed, to perfectly calculate the unconstrained price before this month.

In the data provided by the ISO, these quantities are not represented by bids/offers submitted by operators but they are available as aggregate amounts. Therefore, it is only possible to know that a certain quantity has been bought/sold at a certain hour. This is enough for the computation of the equilibria. This hourly information has been coded as bids/offers and added to the daily public domain bids/offers data (bids at 3000 € and offers at 0 €). This way, the R code, developed to compute the unconstrained market hourly equilibria (NAT), is able to recognize them as orders and take them into account in the construction of the demand and supply curves. Nevertheless, this way of coding the market coupling data does not take into account the hypothesis of market coupling as the price setter.

4.1.3 Day-ahead market unconstrained prices

Information on the unconstrained prices is available on the website of the ISO. This information has been used to check whether the R code was working properly or if some errors had occurred during the computation of the hourly equilibria: if the difference between the actual unconstrained equilibrium published in the ISO's web page and the actual unconstrained equilibrium computed by the R code was zero the hourly equilibrium was considered correct. At the end of this double-check process, it is possible to claim that the R code works properly in 97% (approximately) of the cases. The remaining 3% contains a set of different errors. There are mainly three types of errors that have been recognized: approximation error (thus the difference between the two prices was almost zero), wrong computation of the equilibria when vertical segment intersection occurred and the cases where market coupling was the price setter. In the case where the NAT computed from the R code differed from the one published by GME, the observation was dropped.

4.2 REF-E

Thanks to REF-E[7], which provided extensive information about Italian power plants, it was possible to map a consistent share of power plants and identify their main specifications. Here follows the list of the specifications provided:

- Zone: The macro-area (North, Center North, ...).

- Operator: The operators' names.

[7]Webpage available at: https://www.ref-e.com/it

- Data-in and Data-out: when the power plant started to operate in the liberalized market and eventually when it stopped.

- Technology: The technology involved in the production, for example: Run-of-River hydro, Pumped-Storage, et cetera.

- Energy Efficiency: REF-E estimated the hourly consumption curve of several thermal power plants with a parabolic model (where on the x-axis there is the quantity produced expressed in MW whereas on the y-axis there is the amount of heat, expressed in Gcal/h, that must be generated in order to produce a certain amount of MW).

5 Methodology

The aim of this study is to analyse if the equilibria, that occurred during the four years considered, are the results of a competitive setting or if more competitive equilibria might have been possible. As discussed above, an equilibrium is a pair of price and quantity and it is the results of all the bids/offers submitted. From a theoretical point of view, if all the suppliers were price takers the equilibria would be the perfectly competitive equilibria. In reality, no operator is a price taker. However, the market is characterized by market power asymmetries on the supply side. Thus, there are operators with a limited market share and some other operators with a more consistent market power.

The bidding strategy of an operator includes a variety of different elements: types of plants and their technologies, the amount of plants, the market zone and several other aspects such as markup. Indeed, it is evident from the literature, that strong operators are potentially capable of altering equilibria in order to achieve higher profits. This study aims to analyse what would have happened if leading operators had behaved as small operators. Small operators tend to behave more similarly to a fringe firm rather than a leading operator (see Akgün (2004) and Ciarreta and Espinosa (2010b)). Theoretically, a fringe firm should submit offers that coincide with its marginal costs. A small operator will not submit an offer that exactly coincides with its marginal costs, but its bidding strategy will be closer to its marginal cost than a strong operator. Therefore, the task is to force the leading operators to behave as small operators. This way, it is possible to observe what equilibria would have occurred and investigate if there are any differences between these two sets of equilibria.

In this case study, only one of the largest Italian generators is considered the Leading

Operator (L.O., hereafter) whereas the other firms considered during the data analysis are considered small generators. In order to achieve this goal, a synthetic supply must be computed for every hour. As first step, it is important to define the following expressions:

Actual Supply:

$$S_m^{Total} = \sum_{i=1}^{m} y_i$$

The total amount of offers is given by $\mathbf{y} = (y_1, y_2, ..., y_m)$.

Residual Supply:

$$S_n^{Residual} = \sum_{j=1}^{n} x_j$$

The total amount of offers except the ones of the leading company is given by $\mathbf{x} = (x_1, x_2, ..., x_N)$.

Leading Operator Supply:

$$S_l^{L.O.} = \sum_{k=1}^{l} z_k$$

The total amount of offers submitted by the L.O. are given by $\mathbf{z} = (z_1, z_2, ..., z_L)$. Therefore:

$$S_m^{Total} = S_n^{Residual} + S_l^{L.O.}$$

The crucial point is to create $S_p^{L.O.Synthetic}$ (note that $p \neq l$) such that:

$$S_t^{TotalSynthetic} = S_n^{Residual} + S_p^{L.O.Synthetic}$$

This can be achieved by following the methodological approach proposed by Ciarreta and Espinosa (2010a). It requires two steps: ***association of the plants*** and ***translation of the supply schedule***. The following two subsections are dedicated to this procedure.

5.1 Association of the plants

In the electricity market the marginal costs of the plants depend on several inputs such as: type, technology, vintage, installed capacity and energy efficiency. For this reason, it is reasonable to claim, for example, that the marginal cost of a coal thermal plant built in 1965 does not differ too much from the marginal cost of a plant with the same specifications. Thus, given that the L.O. has a set of plants the task is to find the most similar plants in the market. Therefore, the aim is to associate the highest amount of plants with strict criteria. The stricter the matching criteria are, the smaller the bias will result. Every plant has been matched with at least the criteria of type[8] and technology. Unfortunately, these two criteria

[8]Type: Thermal, Hydro, Wind, Solar, et cetera.

are not strict enough to permit a reliable association process for each power plant. For this reason, in order to allow a reliable matching this procedure has been conducted separately for zero marginal cost plants and for thermal plants.

It is possible to associate zero marginal cost plants using only type, technology, data-in, data-out and zone[9]. The zero marginal costs plants involved in the data analysis are Hydroelectric (only Run-of-River and Storage; Pumped-Storage have marginal costs depending on the type of the pump so they have not been taken into account in the association process) and Wind power plants. The association process for the thermal plants followed different criteria: type, technology, data-in, data-out and energy efficiency. Ciarreta and Espinoza (2010a) proposed vintage as an association criterion. In this paper, the association of thermal plants is based on: type, technology, data-in, data-out and energy efficiency.[10] The latter criterion is not based on an existing literature stream. Indeed, this idea is new. This criteria is based on finding the most similar plant through the energy efficiency curve. Therefore, the competitor's plant with the closest curve to the one of the leading operator's plant has been chosen among the list. This was done by computing the integrals between the selected leading operator energy efficiency curve and the ones of other power plants belonging to competitors. The limitation of this method is that each plant has an interval of production and for the computation of the integrals, between the L.O.'s curve and each other curve, the minimum and maximum production power of the leading operator's plant have been chosen as the extremes of the interval for each integral. At the end of this procedure, a list of integrals is available for each leading operator's plant. The competitor's plant with the lowest integral is chosen for the association.

A further clarification is provided by Figure 3. The figure illustrates an example of the association technique based on the energy efficiency criteria. Assume that in the market there

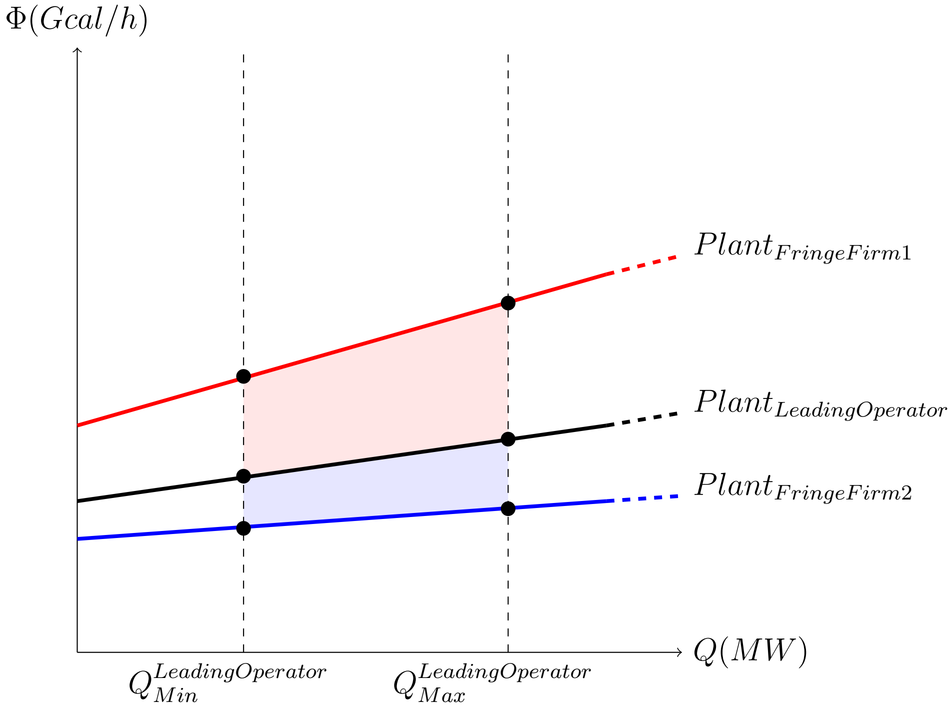
[9] For zero marginal cost plants, the Zone criterion permits to control for the exogenous inputs (for example wind power) as they depend on the geographical zones.

[10] Only a few associations have been made using very similar technologies because the same technologies were not available in some cases.

Moreover, the Zone criterion was not taken into account in the association process of the thermal plants. This can be considered a source of bias as the bidding strategies can be related to the bidding zones. However, Zone criterion would result in a further constraint upon the association process. In fact, it would drastically reduce the amount of power plants available for the association of each L.O.'s power plant. Therefore, it is favourable to identify the most similar plants at a national level than the most similar ones within the same bidding zones. Furthermore, as the analysis focuses on the unconstrained prices, the Zone criterion is less important.

are only three power plants (Black, Blue, Red), with the same technology, having efficiency curves represented by the three straight lines: Black (Leading Operator), Red (Fringe Firm 1) and Blue (Fringe Firm 2). The aim is to find what is the most similar available plant (Red or Blue) in the market to the Leading Operator one (Black). It turns out that the Blue has an efficiency curve more similar to the Black rather then the Red, as the integral computed between Blue and Black is smaller than the one computed between Red and Black. For this reason, the Blue will be chosen as the plant to be associated with the Black.

Figure 3: Efficiency Curves



Overall, approximately 50% of the L.O.'s power plants have been associated.[11][12] At the end of this procedure, each plant of the leading operator has three matched plants: first best, second best and third best. There is the need of a second and third best, chosen with the same association criteria, because it may happen that given a certain hour the first best is not present in the data set. If this happens, it is replaced by the second and the synthetic offer is computed referring to the second best. Obviously, if the second best is missing, the

[11] Due to a data constraint it was not possible to associate the entire set of the L.O.'s power plants reliably.

[12] We assume the unmatched plants would have the same bidding strategy within the synthetic supply curve as in the observed bid stack.

R code looks for the third one. If the third one is not available either, the R code skips the association and proceeds with the following one.

5.2 Translation of the offers

Once the plants have been matched, it is possible to proceed with the "translation" of the bidding strategies. In other words, the aim is to impose the bidding strategy of the competitor to the L.O. . This can be done by changing the bidding schedule of each leading operator's plant with the associated ones. For the sake of simplicity, assume that the aim is to match the plant A (owned by the leading operator) with the plant B (owned by a fringe firm). This procedure requires the following steps:

- Sum the quantity offered by plant B (we get q^B_{tot}). Divide each quantity offered for the total quantity. This way, we will get a vector of proportions that has from one to four entries (each supplier can submit a maximum of four offers from every power plant they own). Define this vector as $q^B_{proportion} = (q^B_1/q^B_{tot}, ..., q^B_o/q^B_{tot})$ with $o \in (1, 2, 3, 4)$.
- Sum the quantity offered by plant A (we get q^A_{tot}). Multiply q^A_{tot} by each entry of $q^B_{proportion}$. This means that the synthetic supply schedule of A will have the same amount of offers submitted by B. This way, the leading operator uses the same bidding strategy of a smaller firm. Therefore, we force the leading operator to behave like a smaller firm.

At the end of this procedure, once that all the offer schedules have been translated, we will get $S^{L.O.Synthetic}_p$. Thus, the synthetic supply is given by:

$$S^{TotalSynthetic}_t = S^{Residual}_n + S^{L.O.Synthetic}_k$$

(note that $t \neq m$).

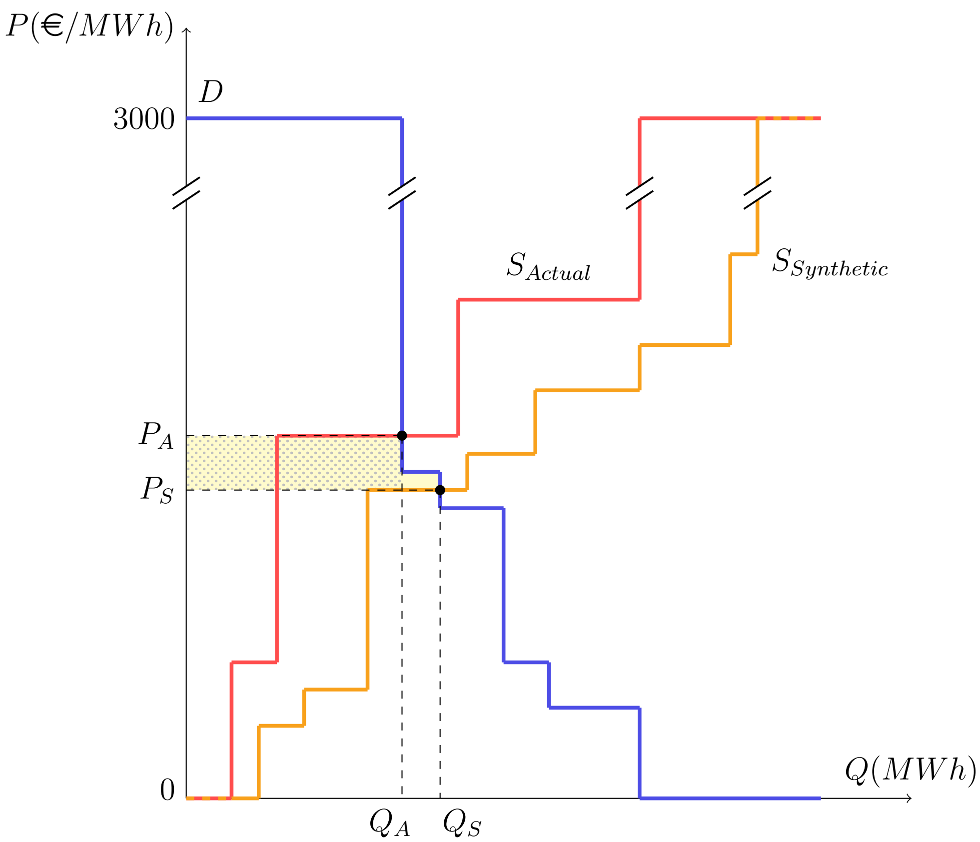
This way, two intersection points are obtained every hour. Next section explains what the aim of the empirical analysis is.

6 Empirical Analysis

Synthetic supply method allows us to obtain two set of different equilibria for each hour. The actual equilibria are the ones that we observe in the real market whereas the synthetic ones derive from the intersection between demand curves and synthetic supplies. The latter are obtained by forcing the leading operator to behave as smaller firms. For this reason it is reasonable to assume that synthetic equilibria are more competitive than the actual ones: lower prices and higher quantities. However, the electricity market is characterized by a very inelastic demand. Thus, only the statement referring to prices seems to be true.

A further clarification is provided by an example illustrated in Figure 4. This plot shows a graphical representation of the methodology proposed above. It shows the two hourly market clearing prices. The actual equilibrium is the intersection point between Demand (in blue) and Actual (in red) whereas the synthetic equilibrium is the intersection point between Demand and Synthetic Supply (in orange). Furthermore, the yellow area represents the consumer surplus loss.

Figure 4: Actual Equilibrium, Synthetic Equilibrium and Consumer Surplus Loss



D:Demand; S_{Actual}:Actual Supply, $S_{Synthetic}$: Synthetic Supply; P_A: Actual Price; P_S: Synthetic Prices; Q_A: Actual Quantity; Q_S: Synthetic Quantity.

The task of the empirical analysis is two-fold: on one hand it investigates if there is any statistically difference in means between the actual prices and the synthetic one whereas, on the other, it computes the consumer surplus loss in order to evaluate the impact of the bidding strategy of the L.O.. Moreover, an alternative version of Lerner Index is presented and discussed. Therefore, the section is divided in three subsections where these results are discussed separately.

6.1 Actual Prices vs Synthetic Prices

The aim is to verify whether actual prices are on average higher than synthetic ones and to test whether the difference is statistically significant. Define the actual prices and the synthetic ones as the following vectors with length 8760[13]:

$$\mathbf{p}^{Actual} = (p_1^{Actual}, p_2^{Actual}, ..., p_{8760}^{Actual})$$

$$\mathbf{p}^{Synthetic} = (p_1^{Synthetic}, p_2^{Synthetic}, ..., p_{8760}^{Synthetic})$$

However not all the hours are in the sample as already explained above.
Now the point is to analyse whether the actual equilibria differ from the synthetic ones. In particular, the scope of this study is to investigate to what extent the actual prices are higher than the ones computed under the assumption of more competitive bidding strategies. Results are presented in the appendix and are organized in four tables, one for each year, containing the means of actual and synthetic prices computed for every month in different intervals of hours. Monthly means of actual and synthetic quantities are presented. Furthermore, the monthly difference in the means of the actual and synthetic prices and quantities are reported. Moreover, Figure A.1 illustrates the trends of the monthly difference in means, between actual and synthetic prices, for total hours, day hours and night hours. Results suggest that actual prices have been significantly higher than synthetic ones. The most outstanding discrepancies occurred during 2017, reaching a peak in monthly difference in means of 8.03 €/MWh (See Table A.2 in the Appendix). It seems that the prices during the day have been slightly higher than the ones occurred by night. However, there are not remarkable differences between the monthly means of day prices and night ones.

Moreover, a t-test has been run on annual prices to investigate if there is a statistical difference in means between actual and synthetic prices. The null hypothesis is rejected for

[13]Except for 2016 that has 8784 hours and 2015 for which the first two months are not taken into account.

every year confirming the hypothesis that the two time series differ in mean. However, it should be pointed out that the main assumptions of the t-test are not met. Thus, in order to get rid of time dependency which compromises the assumption of independent observations and the lack of normal distribution, due to the log-normality nature of prices, of actual and synthetic prices, a bootstrap technique has been implemented. Each annual data set, composed by approximately 8760 pairs of hourly actual and synthetic prices, has been randomly sampled 4000 times. Each sample contains 1000 random observations. The mean of each sample has been computed and the t-test has been run on this new data set. This way, the assumptions of normal distribution and independent observations are not violated.

On the contrary, findings show that there are not statistical differences in means between actual quantities and synthetic ones, due to the inelastic demand. Obviously, synthetic quantities are higher than actual ones.

6.2 Consumer Surplus Loss

In this section the estimates of the consumer surplus losses are discussed. Consumer surplus loss has been computed, for each hour, as the following area[14]:

$$CSL^{Abs} = (P_A - P_S) * Q_A$$

Thereafter, these values have been summed on a monthly and annual basis. Moreover, in order to have a comparative measure that helps to assess the size of the Consumer Surplus Loss, the following measure is proposed:

$$CSL^{Rel} = \frac{(P_A - P_S) * Q_A * 100}{P_A * Q_A}$$

These results are available in the appendix. Ciarreta et al. (2010a) computed the Consumer Surplus Loss as a rectangle trapeze thus adding the triangle area below

$$\frac{(P_A - P_S) * (Q_S - Q_A)}{2}$$

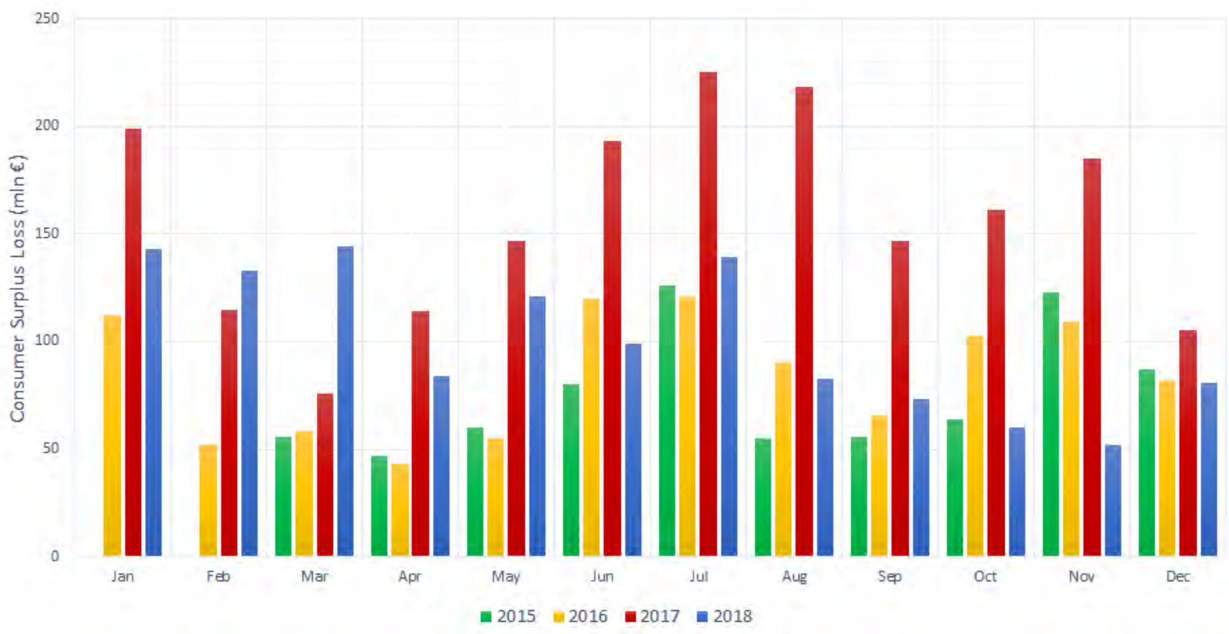
However, the choice of excluding the triangle in the estimates has a double motivation. The first one is that it risks a slight overestimate of the Consumer Surplus Loss. The second one, which is the most relevant one, is that the demand is very inelastic. Thus, the difference

[14] Figure 4 provides a graphical example. The estimated Consumer Surplus Loss is represented by the dotted yellow area.

between the synthetic quantity and the actual one is extremely small. Therefore, the area of the triangle is not significantly affecting the Consumer Surplus Loss.

Results suggest that Consumer Surplus Loss has been constantly increasing from 2015 to 2017 reaching its peak in 2017. From the end of 2017 it seems that this growing pattern slowed down, decreasing significantly in 2018. Figure 5 illustrates the Consumer Surplus Loss over the years of analysis.

Figure 5: Consumer Surplus Loss



The plot illustrates the consumer surplus loss from 2015 to 2018.

January and February 2015 are note reported for the reasons explained above.

The interpretation of these results must be two-fold. In fact, it is appropriate to consider both the general and specific factors. The former refer to events which affect the the regular market dynamics whereas the latter refer to both the data analysis and the case study. The results suggest that the main peaks of Consumer Surplus Loss occurred during the high level of electricity demand. Said levels appear mainly during those months when heating and cooling were necessary. Indeed, when the demand is high, exercising market power may become easier and the main market operators could take advantage of this. However, the complexity of the dynamics that characterize the electricity markets, means that finding a unique general motivation that explains these results is not possible. In fact, the market is constantly affected by internal and external shocks. For example in the first six months of 2016, Consumer Surplus Loss might have reduced as some other market operators increased their revenues. Indeed, from a data point of view Consumer Surplus Loss increases when the L.O. raises its markup and the competitors fail to do so. On the contrary, it decreases in two cases. First of all, if the competitors increase their markup and the one of the L.O. remains fixed the Consumer Surplus Loss decreases. Secondly, if the L.O. decreases its markup and those of the competitors remain constant. However, even if the question remains open, results suggest that a more competitive setting occurred in 2018 compared to the previous year.

6.3 Lerner Index

Ciarreta et al. (2010a) proposed an alternative version of the Lerner Index. In this section, the standard version and the alternative one are presented. Thereafter, results are discussed. The traditional version of Lerner Index is defined as:

$$LI^{Traditional} = \frac{p - mc}{p}$$

The alternative version of Lerner Index is defined as:

$$LI^{Alternative} = \frac{P_A - P_S}{P_A}$$

Where P_A and P_S are respectively the actual and synthetic prices.
This latter version can be consider as a lower bound measure of the standard LI as $P_S > mc$. Results are presented in Table 1. It is crucial to interpret them taking into account that this is a lower bound measure (as the competitors' markup is included in this index) and that only approximately 50% of the L.O.'s power plants have been matched.

Table 1: Average Alternative Lerner Index

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2015	-	-	0.06	0.06	0.06	0.07	0.06	0.04	0.05	0.05	0.08	0.06	0.06
2016	0.10	0.06	0.06	0.06	0.07	0.14	0.09	0.11	0.06	0.08	0.08	0.06	0.08
2017	0.10	0.09	0.07	0.13	0.16	0.17	0.16	0.12	0.14	0.11	0.11	0.08	0.12
2018	0.11	0.09	0.09	0.08	0.09	0.07	0.08	0.05	0.04	0.03	0.03	0.05	0.07

7 Limitations, Strengths and Future Research

Even though this study tried to minimize biases, it is extremely hard to control for some of them. In this section the main sources of bias will be discussed.

The first two limitations refer to the market structure: the unconstrained price (NAT) is considered and only the day-ahead market has been taken into account. Given that NAT does not take into account zonal prices, there is a source of bias, as some information on bidding strategies related to the bidding zones are not considered. However, NAT is an indicator of real prices. On the contrary, the analysis which only focusses on the day-ahead market does not take into account relevant information contained in the successive market sessions. Nevertheless, the day-ahead market is the most relevant market as the largest quantity of electricity is exchanged in this market (approximately 90% of the Spot Electricity Markets).[15] Thus, from this point of view, the analysis cannot be consider complete but is surely important.

The other two main limitations are related to the association process. Indeed, even if the most similar plants have been found and matched with the ones of the L.O., they are just partially representative of the true marginal costs. Moreover, the bias increases with the second and third best as the associated plant will reflect less the technological features of the L.O. power plant. Furthermore, only 50% of the L.O.'s power plants were associated. This is a further limitation as some bidding strategies have not been taken into account. The reason why the other power plants were not matched is related to the lack of a reliable association process or to a data constraint. For these reasons, the results of this case study should not be interpreted as a definitive market analysis but as a starting point for future research.

However, this research contributes to the existing literature by adding new evidence and findings. It is important to point out that this technique partially controls for start-up costs (as they are included in the competitors' bidding strategies). For this reason, they are capable of representing some market dynamics more than other methodologies, as there is a control for start-up costs.

Moreover, the technique of synthetic supply can be applied in several ways [16]. This study focusses only on a case study of market power but the potential of this technique is extremely

[15] For example, in 2017 the total electricity exchanged in the Day-Ahead Market was 292 TWh whereas in the Intraday Markets 25 TWh (see the GME report available in the references.)

[16] See for example Ciarreta et al. (2017) or Ciarreta et al. (2010b)

broad.[17] In particular, synthetic supply could be employed in the computation of competitive benchmarks for the market. Indeed, it will be possible to obtain an estimate of benchmarks of a perfect competitive market if the offers of all the power plants are calibrated on marginal costs. Start-up costs may be included as well in order to achieve a more accurate set of results.

8 Conclusion

Market monitoring is a difficult task, as the electricity market is a dynamic environment, which constantly evolves both from a technological and a regulatory perspective. Therefore the bidding strategies of the operators need to constantly adapt to achieve the best market performance. It is essential to constantly monitor the evolution of these markets in order to bring new evidence, methodologies, suggestions and policy recommendations.

The aim of this article is to provide further evidence on the topic and apply the synthetic supply approach to the Italian electricity market. In fact, this methodology, which does not follow the approach based on the inverse of the residual demand elasticity (see Wolak (2003)), enables us to analyse the Italian electricity market presenting results from a new perspective. Our results seem to suggest that a more competitive setting occurred in 2018 and that the market is experiencing a decreasing market power path, even though the results highlight the presence of persistent and non-negligible Consumer Surplus Loss. However, as previously discussed above, it is important to bear in mind that the question of whether significant market power is being exercised remains open and that a further and deeper analysis is required to extensively monitor the market. For this reason, even though the findings presented are intriguing and contribute to the existing literature, it is appropriate to stress that they are not definitive but rather a further step in developing a deeper and more comprehensive market analysis.

[17]The methodology presented in this paper easily adapts to those markets where the offers are associated with the power plants.

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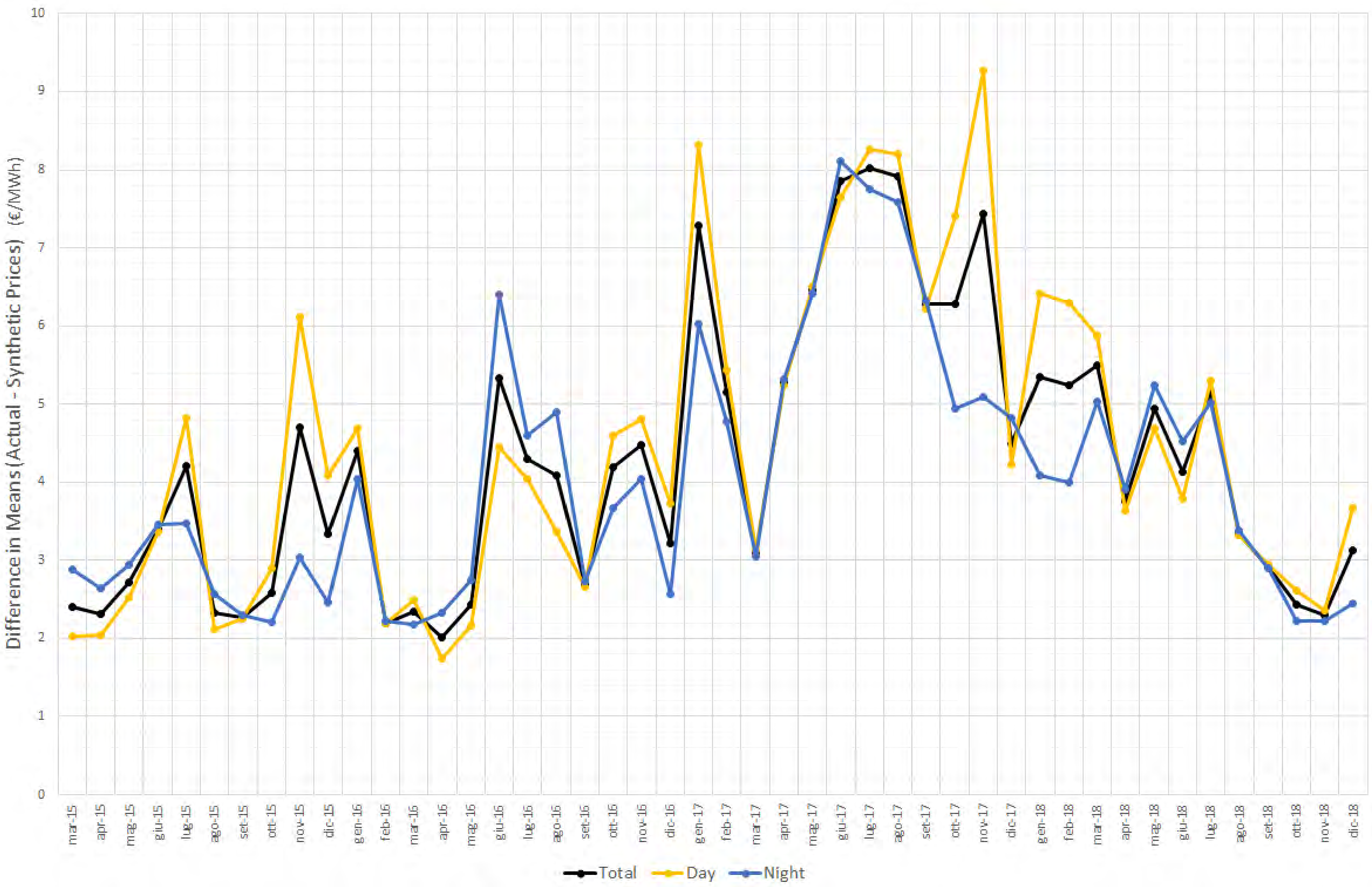
Appendix

Figure A.1: Prices



The plot exhibits three time series. The differences between the monthly actual and synthetic means are reported. The time series in black represent the total hours, the one in yellow represents the day hours (08-20), whereas the remaining one represents the night hours (21-07).

Table A.1: 2018 Results

Period	$\text{Mean}^{A.P.}_{Tot}$	$\text{Mean}^{S.P.}_{Tot}$	Diff^{P}_{Tot}	$\text{Mean}^{A.P.}_{Day}$	$\text{Mean}^{S.P.}_{Day}$	Diff^{P}_{Day}	$\text{Mean}^{A.P.}_{Night}$	$\text{Mean}^{S.P.}_{Night}$	Diff^{P}_{Night}	$\text{Mean}^{A.Q.}_{Tot}$	$\text{Mean}^{S.Q.}_{Tot}$	Diff^{Q}_{Tot}	CSL^{Abs}_{Tot}	CSL^{Rel}_{Tot}
Jan	48.71	43.36	5.35	54.23	47.82	6.41	42.17	38.08	4.09	34515.9	34766.71	-250.81	143 mln	11.26
Feb	56.39	51.14	5.25	61.15	54.86	6.29	50.65	46.66	3.99	35955.3	36219.65	-264.35	133 mln	9.72
Mar	56.79	51.29	5.5	60.84	54.97	5.87	51.8	46.77	5.03	34551.61	34755.83	-204.22	144 mln	9.87
Apr	49.56	45.81	3.75	50.02	46.39	3.63	49.03	45.13	3.9	30791.98	30842.7	-50.72	84 mln	7.62
May	53.83	48.89	4.94	55.45	50.76	4.69	51.9	46.66	5.24	32214.92	32285.93	-71.01	121 mln	9.23
Jun	57.49	53.36	4.13	58.13	54.34	3.79	56.73	52.2	4.53	34347.5	34398.34	-50.84	99 mln	6.94
Jul	62.29	57.13	5.16	62.6	57.3	5.3	61.94	56.92	5.02	36972.43	37081.57	-109.14	139 mln	8.12
Aug	66.53	63.19	3.34	66.57	63.25	3.32	66.49	63.11	3.38	32595.03	32645.91	-50.88	83 mln	5.21
Sep	74.83	71.91	2.92	75.83	72.89	2.94	73.67	70.77	2.9	33674.19	33701.52	-27.33	73 mln	4.01
Oct	73.23	70.79	2.44	76.82	74.21	2.61	68.93	66.7	2.23	33206.61	33310.3	-103.69	60 mln	3.36
Nov	66.52	64.22	2.3	71.84	69.48	2.36	59.65	57.43	2.22	34115.21	34161.64	-46.43	52 mln	3.38
Dec	64.9	61.77	3.13	69.55	65.88	3.67	59.15	56.7	2.45	33581.71	33651.17	-69.46	81 mln	5.1
2018	60.92	56.9	4.02	63.6	59.36	4.24	57.73	53.96	3.77	33867.46	33975.27	-107.81	1.21 bln	6.74

Table A.2: 2017 Results

Period	$\text{Mean}^{A.P.}_{Tot}$	$\text{Mean}^{S.P.}_{Tot}$	Diff^{P}_{Tot}	$\text{Mean}^{A.P.}_{Day}$	$\text{Mean}^{S.P.}_{Day}$	Diff^{P}_{Day}	$\text{Mean}^{A.P.}_{Night}$	$\text{Mean}^{S.P.}_{Night}$	Diff^{P}_{Night}	$\text{Mean}^{A.Q.}_{Tot}$	$\text{Mean}^{S.Q.}_{Tot}$	Diff^{Q}_{Tot}	CSL^{Abs}_{Tot}	CSL^{Rel}_{Tot}
Jan	68.18	60.9	7.28	75.65	67.32	8.33	59.27	53.24	6.03	35064.4	35245.41	-181.01	199 mln	10.89
Feb	54.93	49.78	5.15	58.95	53.51	5.44	49.81	45.03	4.78	34913.02	35084.78	-171.76	115 mln	9.3
Mar	44.24	41.14	3.1	46.03	42.9	3.13	42.05	39	3.05	33180.27	33283.97	-103.7	76 mln	7.04
Apr	42.8	37.52	5.28	42.83	37.58	5.25	42.77	37.45	5.32	30147.86	30274.72	-126.86	114 mln	12.43
May	42.7	36.24	6.46	43.19	36.69	6.5	42.13	35.72	6.41	31264.05	31334.77	-70.72	147 mln	14.83
Jun	47.47	39.61	7.86	48.53	40.89	7.64	46.23	38.11	8.12	34985.48	35046.54	-61.06	193 mln	15.82
Jul	49.11	41.08	8.03	49.47	41.2	8.27	48.7	40.95	7.75	37087.09	37189.2	-102.11	225 mln	16.38
Aug	54.03	46.11	7.92	54.75	46.54	8.21	53.19	45.61	7.58	32594	32688.36	-94.36	218 mln	16.01
Sep	47.87	41.59	6.28	49.4	43.18	6.22	46.07	39.74	6.33	32970.17	33120.23	-150.06	147 mln	12.78
Oct	54.93	48.65	6.28	58.77	51.36	7.41	50.4	45.45	4.95	32014.48	32326.36	-311.88	161 mln	12
Nov	64.42	56.99	7.43	71.48	62.21	9.27	55.5	50.41	5.09	34198.62	34467.63	-269.01	185 mln	12.17
Dec	63.24	58.74	4.5	69.34	65.12	4.22	55.84	51.01	4.83	33384.54	33571.06	-186.52	105 mln	6.73
2017	52.74	46.43	6.31	55.64	48.98	6.66	49.27	43.38	5.89	33473.45	33624.95	-151.5	1.89 bln	12.09

Table A.3: 2016 Results

Period	$\text{Mean}^{A.P.}_{Tot}$	$\text{Mean}^{S.P.}_{Tot}$	Diff^{P}_{Tot}	$\text{Mean}^{A.P.}_{Day}$	$\text{Mean}^{S.P.}_{Day}$	Diff^{P}_{Day}	$\text{Mean}^{A.P.}_{Night}$	$\text{Mean}^{S.P.}_{Night}$	Diff^{P}_{Night}	$\text{Mean}^{A.Q.}_{Tot}$	$\text{Mean}^{S.Q.}_{Tot}$	Diff^{Q}_{Tot}	CSL^{Abs}_{Tot}	CSL^{Rel}_{Tot}
Jan	45.91	41.51	4.4	50.3	45.61	4.69	40.69	36.65	4.04	33584.11	33837.27	-253.16	112 mln	9.45
Feb	36.99	34.79	2.2	40.12	37.93	2.19	33.3	31.08	2.22	34417.37	34568.99	-151.62	52 mln	5.7
Mar	35.13	32.79	2.34	37.12	34.63	2.49	32.74	30.56	2.18	32999.98	33136.89	-136.91	58 mln	6.71
Apr	31.7	29.69	2.01	32.15	30.4	1.75	31.17	28.84	2.33	31376.54	31473.04	-96.5	43 mln	5.96
May	34.17	31.74	2.43	34.29	32.12	2.17	34.04	31.29	2.75	31196.25	31266.61	-70.36	55 mln	6.84
Jun	36.43	31.09	5.34	36.92	32.48	4.44	35.87	29.47	6.4	32437.75	32583.73	-145.98	120 mln	14.3
Jul	42.83	38.53	4.3	43.47	39.43	4.04	42.07	37.47	4.6	36484.11	36577.24	-93.13	121 mln	10.23
Aug	36.97	32.89	4.08	36.75	33.38	3.37	37.22	32.32	4.9	30255.19	30360.99	-105.8	90 mln	10.71
Sep	41.56	38.87	2.69	43.03	40.37	2.66	39.82	37.09	2.73	33566.13	33642.99	-76.86	66 mln	6.62
Oct	51.97	47.78	4.19	55.56	50.96	4.6	47.47	43.8	3.67	32603.97	32719.73	-115.76	103 mln	8.35
Nov	56.55	52.07	4.48	61.36	56.55	4.81	50.5	46.46	4.04	34122.58	34194.3	-71.72	109 mln	8.03
Dec	54.68	51.47	3.21	58.29	54.57	3.72	50.18	47.61	2.57	33875.29	33943.94	-68.65	82 mln	6.17
2016	41.95	38.49	3.46	44.06	40.65	3.41	39.43	35.89	3.54	33067.07	33183.03	-115.96	1.016 bln	8.24

Table A.4: 2015 Results

Period	$\text{Mean}_{Tot}^{A.P.}$	$\text{Mean}_{Tot}^{S.P.}$	Diff_{Tot}^{P}	$\text{Mean}_{Day}^{A.P.}$	$\text{Mean}_{Day}^{S.P.}$	Diff_{Day}^{P}	$\text{Mean}_{Night}^{A.P.}$	$\text{Mean}_{Night}^{S.P.}$	Diff_{Night}^{P}	$\text{Mean}_{Tot}^{A.Q.}$	$\text{Mean}_{Tot}^{S.Q.}$	Diff_{Tot}^{Q}	CSL_{Tot}^{Abs}	CSL_{Tot}^{Rel}
Jan	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Feb	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mar	50	47.59	2.41	53.69	51.66	2.03	45.51	42.63	2.88	32982.84	33109.65	-126.81	56 mln	4.53
Apr	47.88	45.56	2.32	47.18	45.13	2.05	48.73	46.09	2.64	30752.92	30854.31	-101.39	47 mln	4.54
May	47.06	44.34	2.72	46.75	44.22	2.53	47.43	44.49	2.94	30447.27	30567.53	-120.26	60 mln	5.58
Jun	48.58	45.18	3.4	49.13	45.76	3.37	47.94	44.49	3.45	32757.09	32925.55	-168.46	80 mln	6.89
Jul	67.15	62.95	4.2	68.69	63.87	4.82	65.33	61.86	3.47	37632.68	37835.61	-202.93	126 mln	6.53
Aug	53.14	50.81	2.33	52.18	50.06	2.12	54.27	51.7	2.57	30172.98	30261.28	-88.3	55 mln	4.56
Sep	49.32	47.05	2.27	51.63	49.38	2.25	46.58	44.28	2.3	33692.97	33822.41	-129.44	56 mln	4.63
Oct	47.56	44.98	2.58	51.54	48.64	2.9	42.81	40.6	2.21	32374.67	32540.35	-165.68	64 mln	5.52
Nov	53.65	48.94	4.71	60.41	54.29	6.12	45.56	42.53	3.03	33016.03	33248.29	-232.26	123 mln	9.27
Dec	55.17	51.83	3.34	60.89	56.8	4.09	48.42	45.96	2.46	32529.6	32735.95	-206.35	87 mln	6.28
2015	52	48.96	3.04	54.25	51.02	3.23	49.31	46.52	2.79	32640.88	32795.13	-154.25	0.760 bln	5.92