The RES-Induced Switching Effect Across Fossil Fuels: An Analysis of Day-Ahead and Balancing Prices

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ABSTRACT

The empirical literature on electricity markets have highlighted a strong cointegrating relationship governing the dynamics of electricity and fuel prices. More recently the massive introduction of RES in electricity generation, fostered by generous supporting schemes, has influenced the shape and position of the supply function and consequently the equilibrium prices. We believe that the new competitive scenario may have influenced the fuel-electricity nexus with a different impact in day-ahead and balancing markets. Empirical evidence of the evolving fuels-electricity nexus is show looking at one Italian zone across two samples characterized by a significant change in the level of RES penetration. We conduct the analysis taking into account both day-ahead and, for the first time, balancing market sessions. Results indicate that fuel prices are much less relevant in determining the dynamics of electricity prices in recent years characterized by high RES penetration. On the contrary, taking into account flexible thermal sources, we show that in the second sample balancing and fuel prices (especially gas) are in a long run equilibrium.

Keywords: Renewable Sources, Electricity, Coal, Oil, Gas, Cointegration

1. INTRODUCTION

In this paper we show how the increased electricity generation from Renewable Energy Sources (RES-E) has influenced the well known relationship linking the dynamic behavior of fuels and electricity prices. The evidence is obtained using Italian market data for day-ahead and, for the first time to our knowledge, balancing market prices. The analysis of real time sessions is particularly relevant in years when the high RES penetration has reshaped competitive conditions in the electricity markets. Balancing activity is extremely important for system security, given the intermittent and unpredictable nature of wind and solar sources. Moreover, balancing sessions have become a source of cost for Transmission system operators (TSOs), that are the formal responsible of system security, grid stability and instantaneous balance between inflows and outflows[1].

Day-ahead sessions are generally liquid markets where all production units are entitled to make offers. The resulting aggregated supply function is obtained as a merit order of bids which should reflect marginal generation costs of a large portfolio of technologies. On the contrary, balancing sessions are dominated by flexible thermal and hydro technologies. Hence, regulation services are supplied by units usually enjoying a degree of market power which is higher in balancing than in day-ahead sessions, because of the competition with a larger technology portfolio including RES-E

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[1] TSOs perform their tasks by negotiating regulation services in balancing market sessions with producers and/or consumers, remunerating increments or decrements in production and consumption. Furthermore, its market design and power characteristics vary across countries even if a convergence process is taking place for a unique EU balancing area (see ACER, Recommendation No 03/2015).

units. It must be recognized that in the last years lower margins gained on the day-ahead market have changed the opportunity cost for thermal plants to participate to less competitive balancing sessions. Therefore, in this paper we look at both market sessions to gain a global view on how new market conditions have influenced electricity price dynamics.

In this new scenario, we expect that electricity prices should be governed by new drivers with respect to the last decade. Indeed, we expect two distinct evolutionary dynamics of the fuels-electricity nexus induced by the significant growth of RES sources. On one hand, we expect a less pronounced relationship among day-ahead electricity prices and fuel prices (oil, gas and coal); on the other hand, we expect a stronger nexus between balancing and fuel prices. Indeed, prices in the latter sessions may be strongly affected by the increasing need of continuous balancing of demand and supply induced by new and intermittent RES-E generation. However, in these recent years we also witnessed other relevant facts which might have influenced market conditions, like decreasing gas and coal prices, demand contraction and increased market interconnections. All these events might influence the shape of the day-ahead market supply, but the sudden RES penetration is documented to be the main responsible of its displacement. We believe that the right shift of supply (also called "the merit order effect" of RES) is not only lowering electricity prices across the EU, but also changing the nexus between fuels and electricity prices. More specifically, we expect a change in the relative importance of fuels especially on balancing prices, given that the *control* or *regulation power* is mainly granted by gas-fired plants.

We analyze these issues studying the most relevant portion of the Italian market as a reference case, but our findings can be easily generalized to other countries with similar market structures, pricing mechanisms and portfolio mix of balancing technologies. The Northern zone of Italy is historically characterized by high hydro shares and, in the last few years, by high solar photovoltaic (PV) penetration. It is connected with several foreign countries for which a market coupling has been implemented, and its zonal generation represents more than a half of national production. Hence, this zone is a good candidate[2] to analyze the influence of RES on relations between electricity and fossil fuels.

We focus on a time span from 2006 to the end of 2015 during which we observed a progressive increment of RES generation from low or even absent to high penetration. However, on the same horizon, there were few important facts: relevant regulatory changes (regarding intra-day and balancing market sessions) have been introduced in the period 2009-2012, and also a financial crisis occurred, which affected the demand of electricity and it modified the intra-daily profile[3]. Therefore, we decided not to analyze this period because it is characterized by a transition towards a new market design and a new technology portfolio, and hence we expect that the relationship among variables of interest to be unstable; this has been anticipated by Cló et al. (2015). Hence, we have divided the time series into two samples: the first one (2006-2008) representing a scenario with low RES penetration and low competition, whereas the second one (2013-2015) representsing a scenario with high RES penetration and high competition. Using dynamic econometric models, we study the relationship between fuels and electricity prices for both day-ahead and balancing market sessions across the two selected samples. The empirical analysis suggests that a *switching effect* has occurred in the day-ahead market, where RES penetration has decreased the role of fuels in explaining the dynamics of price . Moreover in the new competitive scenario, gas prices are found to be less relevant while coal prices become the main driving force of electricity price variability. The phenomenon is particularly evident

[2]Another interesting case would be the Southern zone, characterized by high wind penetration, but limited transmission capacity. However, a low number of trades in Southern balancing market sessions were observed. Indeed, Gianfreda et al. (2018) document that in this zone, 'accepted' and 'no revoked' auctions in the MB session were available only for some hours over the latest years 2013-2015. Furthermore, the inspection of MSD and MB data showed that accepted bids/offers on these market sessions were very thin. Therefore, the available information is not sufficient to analyze properly the time series of these prices.

[3]The dynamics of intra-daily profiles for demand over considered years are omitted for lack of space but are available on request.

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at specific hours, like for example at sunset. We ascribe this result to the "merit order effect". Results related to the analysis of balancing prices are quite different. First, they are only mildly related to fuel prices in the long run. In the same manner, the switching effect exists but is limited and restricted to some hours only. Therefore, we decided to further investigate this nexus in balancing sessions taking into account accepted bids submitted from flexible thermal sources only. Looking at these prices, we find that fuels and electricity prices share common dynamics in real time market sessions in the second sample. We believe this is the evidence of a new role played by thermal units as supplier of flexibility and we interpret our results in terms of evolving market opportunities: thermal units are often excluded from the day-ahead market, being price-setter less frequently than in the past as consequence of a more competitive environment, and we believe that they try to recover profits in balancing sessions, where RES sources are not allowed to bid. However, balancing prices are not entirely cost-reflective and appear to be driven also by strategic considerations related to the high degree of market concentration, as we discuss later observing the price statistics of submitted offers to sell electricity. The paper is structured as follows: Section 2 reviews the main results obtained in the related literature, Section 3 provides a description of the structure of the Italian power market, whereas data, methodology employed and our empirical results are presented in Section 4. Finally, Section 5 concludes.

2. LITERATURE REVIEW

Soon after the creation of wholesale electricity markets, the issue of price series dynamic behavior and forecasting became of paramount importance. The empirical analysis however concentrated on day-ahead market prices only and, until now, there is a lack of evidence about leading forces governing the dynamics of balancing prices. Starting from De Vany and Walls (1999), one stream of literature applies cointegration analysis to electricity price series and tests for integration of regional markets. Bosco et al. (2010) find strong evidence of a common long-term dynamics between electricity and gas prices for the major EU power exchanges. This long run common dynamics is one of the key factors explaining the almost strong integration among price series of the different power exchanges. Huisman and Kilic (2013) study the dynamic behavior of prices under normal and not-normal market conditions applying regime-switching models. They found evidence of convergence among EU markets due to increasing connectivity and improved liquidity. More recently, Weron (2014) discusses the main methods and results of applied papers on electricity prices forecasting. Other papers, like Nomikos and Andriosopoulos (2012), model energy spot price series extending the analysis to different market and including various energy products, like electricity, oil and gas. Several authors have studied the relationship between RES-E and electricity prices all around the world, as in Texas, Australia, Spain, Denmark, Norway, United Kingdom, The Netherlands and Germany[4]. Taking into account the Italian case, Gianfreda et al. (2016a) study the dynamic of day-ahead and balancing prices supporting the view that price spreads depend positively upon quantities generated by hydro, wind, solar and geothermal sources. At the same time, Gianfreda et al. (2016b) look at the relationship between day-ahead electricity prices, gas and coal prices in several EU countries, showing that the modified nexus has affected the creation of an internal energy market for Europe.

The analysis contained in the present paper presents new interesting insights with respect to both Gianfreda et al. (2016a) and Gianfreda et al. (2016b). The former contribution investigates the dynamics of prices formed in different market sessions and the *premium of readiness* granted to flexible units. The analysis does not consider the relationship among electricity and fuel prices, which is the main goal of the present paper. In the latter one, the relationship among fuels and electricity prices is investigated but for day-ahead sessions only, without any reference to balancing sessions, which on the contrary are considered in this paper. Another important difference is related

[4]See for instance Woo et al. (2011), Ketterer (2014), Mulder and Scholtens (2013), Mauritzen (2013), Cutler et al. (2011), Gelabert et al. (2011), Blazquez et al. (2018) and Cruz et al. (2011) among many others.

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to the choice of hours which are now extended to include ramping-up and down. Ramp-down hours are particularly interesting to detect the effect of disappearing solar-PV production, which must be replaced by flexible production at sunset. More generally, the increasing share of RES-E supplied in day-ahead market sessions, with priority of dispatch over other sources, has produced the so-called merit-order effect highlighted by Cló et al. (2015): residual demand for conventional (especially gas) units in day-ahead sessions becomes very tight in an increasing number of hours. Moreover, they find evidence of a model change between years 2006-08 and 2012-13, motivated by the impact of the financial crisis; which supports our decision about sample periods considered in this analysis. Blazquez et al. (2018) recognize that promoting RES in currently liberalized markets may create a paradox, since future deployment of renewable energy will necessarily be more costly and less scalable. Paradoxically, in order for renewable technologies to continue growing their market share, they need to co-exist with fossil fuel technologies.

If thermal units are price setters in a smaller number of hours then it is very likely that equilibrium prices decouple from fuel prices as the share of RES increases. Therefore, increasing RES and decreasing role of fuels in explaining the dynamics of electricity prices should be two sides of the same coin. As interruptible RES gain ground in day-ahead sessions at the expenses of thermal generators, more balancing needs emerge near the time of delivery, which require flexible production units able to guarantee system security. For this reason, balancing markets are attracting an increasing interest in the last years, both in the literature and in regulatory activity. To our knowledge, there is a lack of evidence on the dynamic behavior of balancing prices and about their leading forces. Price series of real time sessions are difficult to analyze and compare across countries due to different market mechanisms used to supply flexibility. At the same time, balancing prices are determined using the pay-as-bid rule and a reference price is constructed as a weighted average of all accepted bids. For these reasons, day-ahead and intra-day prices appear to move very closely, whereas balancing prices behave differently (see Gianfreda et al., 2016a for a detailed analysis).

From a theoretical point of view, auction theory provides testable hypotheses about the linkage between costs and bids. The mark-up of bids over costs depends upon auction rules and market behavior. Ausubel et al. (2014) analyze bidding behavior in uniform-price and pay-as bid mechanisms in the case of multiple units auctions. They prove that uniform-price auctions are characterized by differential bid shading when bidders have multiple units to buy/sell[5]. On the contrary, in pay-as-bid (first-price) auctions the amount of bid shading is not related to the quantity supplied. Theoretical results applied to balancing markets imply that accepted bids should be cost-reflective up to a constant mark-up so that they should co-move with marginal (fuel) costs for thermal units. This linkage however has not been tested until now.

The literature on balancing markets does not concentrate on price series but analyzes other interesting features. A number of recent papers consider different institutional designs and their ability to respond to high and increasing RES penetration, as for example Hirth and Ziegenhagen (2015) and Ocker and Ehrhart (2017) in the German case. Among others, Fernandes et al. (2016) consider the participation of RES in the Spanish balancing market, analyzing the current market design and suggesting the adaptation of balancing arrangements. Indeed, the Spanish government recently launched a new remuneration scheme providing renewable generators strong incentives to participate actively in all electricity markets sessions, including the balancing ones. While in other countries transactions are organized with continuous trading mechanism, in Italy and Spain a number of organized adjustment market sessions allows producers, including RES-E units, to update their schedules as better forecasts become available. Gianfreda et al. (2016a) and Chaves-Avila and Fernandes (2015) show that in both countries respectively, intra-day markets have effectively contributed to balance renewable generation even if market design leaves room to possible strategic behavior across sessions, giving rise to higher system costs emerging in the balancing phase.

[5]This means that the mark-up is increasing both in the quantity sold by the firm and production costs.

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3. BACKGROUND ON THE ITALIAN POWER MARKET AND ITS BALANCING

The Italian Power Exchange (IPEX) is organized in the day-ahead, intra-day and ancillary service markets. The day-ahead market (*mercato del giorno prima*, MGP) is the wholesale marketplace where demand/supply bids are submitted for the delivery of physical energy for each hour of the following day. It works under the marginal pricing rule and the equilibrium price is unique on all the territory and islands in the absence of line congestions[6]. The *Gestore dei Servizi Energetici*[7] (GSE) sells RES-E production on the MGP, and it enjoys priority dispatch. Therefore, the relevant portion of demand open to competition of all other conventional units is residual with respect to quantities allocated first to RES units. The combination of low demand and evolving productive mix produced two main effects on the MGP: on one hand, we registered a decrease in average hourly prices; on the other hand, we registered a change in the marginal technology, with an increase in the proportion of hours in which coal plants were price setters (from 7% in 2013 to 12% in 2015) at the expense of CCGT plants. Intra-day sessions take place after gate closure of MGP and they are organized as auctions with uniform price rule.[8] The final session is the balancing market, where TSOs refine any deviations from production and consumption plans that occur after the gate closure of the intra-day market. A fundamental point that needs to be emphasized is related to the different generation mix characterizing different market sessions: while in MGP all technologies are allowed to participate, the mix of technologies bidding in balancing sessions is limited to those endowed with the required degree of flexibility, like thermal and hydro. Whereas, RES units do not participate in real time sessions. This observation is an important fact to take into account when contrasting the results emerging in the two sessions.

The increasing RES-E has added uncertainty to planned volumes on MGP, given that its session opens nine days before the day of delivery and closes at 12:00 p.m. of the day before delivery. As a consequence, the quantities bid by solar and wind units are based on forecasts while the effective load is known only in real time. This determines a higher level of volatility in production, which has to be hedged with the reserves for real time balancing. However, five intra-day market sessions (MIs) take place between MGP and balancing sessions. Furthermore, the seasonality of solar production lowers demand available for conventional technologies during hours of irradiation and then requires a strong increase in programmable and flexible production at sunset. For this reason, the evening ramp has increased from 8,250 MW in 2012 to 11,050 MW in 2014, a fact that produced a significant impact in the balancing market.

The ancillary service market (*mercato dei servizi di dispacciamento*, MSD) opens at 12:55 p.m. of the day before delivery. It consists of a scheduling sub-stage ("ex-ante MSD" with 4 sessions) and a balancing market (MB) with 5 sessions. MSD is the marketplace where the Italian TSO, Terna, negotiates all resources necessary to guarantee the system security, including dispatching services useful for resolving intra-zonal congestions, the establishment of an adequate reserve and real time balancing. The ex-ante MSD and MB are based on the "pay-as-bid" pricing mechanism. A reference price is computed as the quantity-weighted average of all accepted bids, for both purchases and sales. In the ex-ante MSD, Terna accepts energy demand bids and supply offers in order to relieve congestions and to create reserve margins. During MB sessions, Terna accepts energy demand bids and supply offers in order to provide its service of secondary control and to balance energy injections into and withdrawals from the grid in real time. Furthermore, it is possible to distinguish between 'upward' reserve (for balancing capacity/energy procured to compensate a negative imbalance) and

[6]When congestions occur, zonal configurations emerge as consequence of market splitting and the price paid to producers differs across zones.

[7]GSE is a public company acting on behalf of the Italian Ministry of Economic Development. It manages all the activities related to RES, from the units' qualification as "green producers" to the selling of electricity produced by RES units in the MGP.

[8]Prices observed in intra-day sessions are closely related to those observed in the corresponding MGP sessions. See Gianfreda et al. (2016a) for a detailed analysis.

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'downward' reserve (for balancing capacity/energy procured to compensate a positive imbalance). Bids submitted in MB sessions can only contain better economic conditions with respect to MSD bids, otherwise ex-ante MSD bids remain valid. Italian suppliers of balancing power are obliged to deliver energy under fixed technical conditions, like time of response, ramp rates and duration.

The increment of RES-E in MGP and the related displacement of conventional technologies have produced relevant consequences not only in the MGP itself (see Bigerna et al., 2016; Sapio, 2015), but even in the downstream market segments, where energy is exchanged close to the time of delivery and only qualified (thermal, hydro and water pumping) units are allowed to bid. In addition, in the last three years, we assisted to the dismissal of old thermal units, not replaced by new and more efficient ones, which reduced the total power entitled to act in MSD (from 73.5 to 70 GW, with the thermal segment registering the main reduction from 60 to 56.6 GW), hence increasing the market concentration with the possibility for balancing units to exploit market power and undertake speculations, with economical consequences in terms of costs for the system.

We consider the North zone of Italy for the following main reasons: it accounts for half of the Italian production, it is well connected with other foreign zones, and more importantly it has been historically characterized by high hydro shares and, in the last few years, by high solar PV penetration; given that RES are not equally spread on the Italian territory (see Gianfreda et al., 2016a). Hence, the influence of RES on long-run relations between electricity and fossil fuels may be relevant.

4. DATA, METHODS AND RESULTS

4.1 Data Description and Preliminary Analysis

Our analysis aims at assessing the interdependence of fuel prices and electricity prices, taking into account both day-ahead and balancing sessions. To this aim, we consider several factors that may have influenced this nexus. Specifically, we inspect the generation mix together with RES-E amounts, the marginal technology index, physical flows, collected from the Italian system operator, *Gestore dei Mercati Energetici* (GME); and, the system load, collected from the Transmission System Operator, Terna Spa, and ENTSO-E[9]. Furthermore, to inspect the effect of fuels on electricity prices, Brent crude oil, coal and ICE UK natural gas prices have been collected from Datastream and converted in €/MWh.

The investigation of the Italian power generation mix shows that it has substantially changed in the last five years[10]. RES sources, except hydro, were absent in 2006 whereas, in 2012, solar production covered more than 7% of Italian demand for electricity, reaching 9% of total generation in 2015. On the contrary, wind increased from 1% to 5% across the two samples. More generally, wind, solar and biomass shares in power generation increased substantially in a time span of few years, whereas hydro production remained stable around 16% all over 2006-2015, but variable according to water availability (from 13% in 2007 to 22% in 2014) and with a modest increment of 4% from the first to the second sample. At the same time, the share of conventional thermal power plants dropped from 80% to 48% in the period 2012-15. Among fossils, gas primarily drives the generation, followed by coal, oil and mixed fuels, whereas no nuclear generation is available. On the whole, conventional sources (gas, coal and oil) decreased their impact by 20% from 2010 to 2015, while RES sources steadily increased their share, accounting for 42.9% of total purchases at the end of 2014; later decreased to 34% in 2015. The role of conventional generation sources was further reduced by the effect of the economic crisis: MGP registered a decrease in demand levels in almost all hours. Electricity consumption decreased by 7% from 2006 to 2013, and by 8% from 2008 to 2015. This

[9]ENTSO-E is the European Network of Transmission System Operators for Electricity, providing support and co-ordination across all over Europe. Further details and data are available at `www.entsoe.eu`. Other relevant sites are `www.mercatoelettrico.org` for GME and `www.terna.it`.

[10]A detailed description and data analysis is provided by Gianfreda et al. (2018), in particular see Figure 2 therein.

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inspection suggests us to conduct our study considering two separate samples: 2006-08 and 2013-15.

Looking for possible disruptions affecting the demand side, we have also analyzed the intra-daily dynamics of national load (generally considered a good proxy for demand) over selected years. Its analysis shows that the financial crises heavily affected the demand for electricity in years 2009-2011 and changed the profile in 2011. As shown by Cló et al. (2015), the demand reduction due to the financial crisis induced a model break that lasted until 2013, and we provide econometric support to our selection in Appendix A. To account for the different configurations of daily demand levels, we consider electricity prices determined at specific hours. An appropriate choice of hours is relevant to isolate effects on electricity prices induced by demand from the those due to RES production. Therefore, following Gianfreda et al. (2016a) and Gianfreda et al. (2018), we consider hours 3-5 for the lowest loads, hours 11-12 for midday peaks, and hours 18-20 for evening peaks. Then, to detect the effect of solar PV, wind and hydro, we have selected hours 11, 13, 19, whereas hour 3 allows us to control for low values of load and RES-E generation. Furthermore, we decided to include hours 9 and 21 (not investigated before) since they represent the ramp-up and ramp-down hours, during which demand noticeably increases/decreases. These allow us to detect the solar effect: irradiation is increasing at hour 9 and quickly falling at sunset, then making conventional generation essential for balancing the system.

To complete the preliminary analysis, we have inspected the yearly dynamics of physical transits across national and international zones. Northern Italy has been a net importer from foreign countries, and an exporter towards Central North. More specifically, over 2006-2008, North imported electricity from foreign virtual zones (like neighbouring countries in North-East and North-West, later become inactive) and from two poles of limited production (Monfalcone and Turbigo-Ronco, with the latter one become later inactive). Over the second sample, North became a net importer from Switzerland, France, Slovenia and Austria; with an average of 21, 18, 3.7 and almost 2 TWh, respectively. Then, over the two considered samples, we assisted to a reduction of imports from 52 to 46 TWh (averages over the corresponding samples). The most dramatic change is observed over exports. Interestingly, Northern Italy sharply reduced its exports towards Central North over the second sample (from 16 TWh in 2008 to less than 2 TWh in 2015). This reduction in quantities exported towards the neighbouring national zone may be induced by new RES-E generation together with new transmission capacity available between Central North, Central South and Sardinia. This effect can be seen more clearly in the intra-daily profiles for net flows[11]: despite upward shifts of import curves during 2013 and 2014, we assisted to a complete change in 2015 with high imports in off-peak hours and higher values in late evening, recalling the "duck curve" for net demand. Obviously, high levels of net imports and the new RES-E generation may have induced shifts towards the right of the supply curve, to which the demand reduction contributed in lowering further the equilibrium prices determined in the day-ahead market.

The changed market conditions have affected the *marginal technology index* (MTI) representing the technologies determining the system marginal price on the day-ahead market (MGP). Its dynamics across hours and years is shown in Figure 1, indicating that foreign zones, market coupling and RES sources where price setters in the MGP in period 2013-15; with higher frequencies with respect to 2006-08. We also notice that gas maintained and even increased its relevance at hours 19 and 21, when solar production disappears. This analysis further supports our decision to consider at the same time natural gas and oil[12]. In fact, its inspection highlights the following facts that have to be considered for modeling purposes. First, turbogas TG technology exhibits quite low percentages in determining the Northern zonal prices (from 0.27% observed during several hours and across most years, to 0.82% during hour 11 in 2013), and, for this reason, this technology has been merged with the predominant CCGT. Coal, natural gas, as well as oil, appear to be important fuel drivers (there are

[11] Net flows have been computed as absolute values of the sum of imports and exports and their yearly dynamics across the 24 hours are omitted for lack of space but available on request.

[12] For further discussion and analysis see Gianfreda and Grossi (2012).

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indeed several plants running with mixed fuels both in day-ahead and in balancing market sessions). Natural gas and oil have lost shares in the day-ahead market across the two samples and similarly water pumping, which lost shares in the second sample especially during ramp-up and ramp-down hours[13].

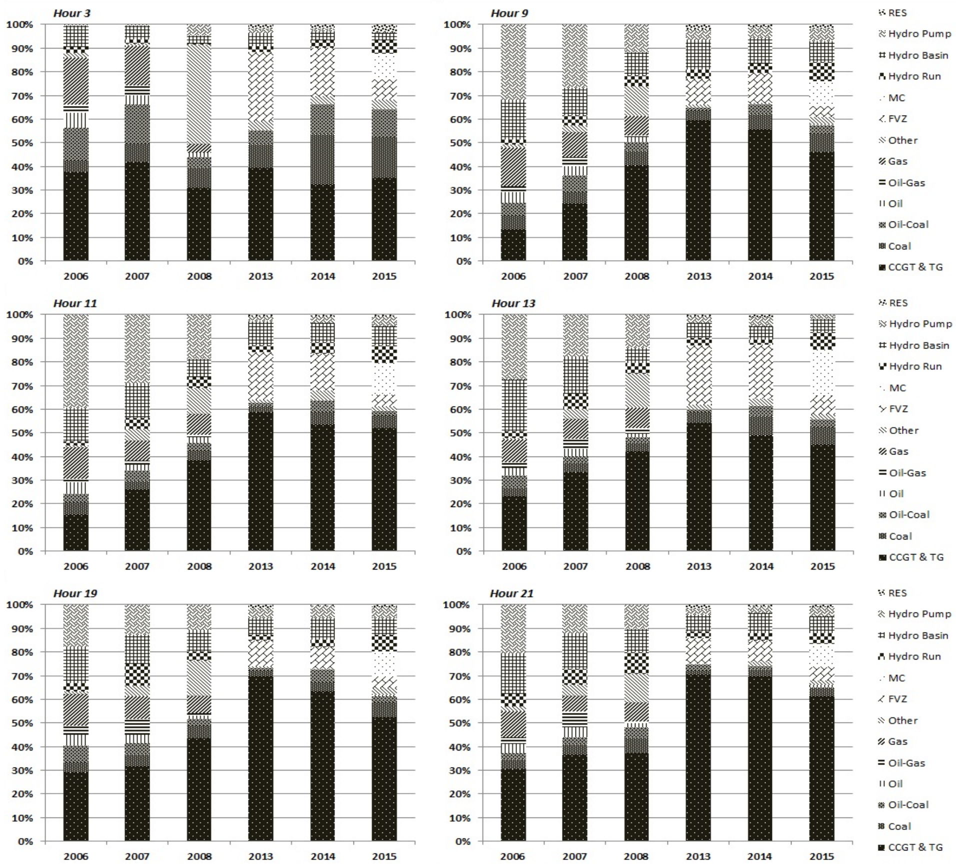

Figure 1: Percentages of the Marginal Technology Index on the day-ahead market (MGP) in Northern Italy. 'Foreign and virtual zones' and 'market coupling' are indicated by FVZ and MC, respectively.

Turning to the balancing market and taking into account the *pay-as-bid* pricing mechanism applied in real time auction sessions, we have computed the balancing prices weighted for the corresponding awarded quantities within each technology, hour and day. We repeated this aggregation for purchases and sales awarded on the ex-ante MSD and MB sessions. Finally, we computed the weighted awarded prices using bids "accepted" on MSD and "not revoked" on MB[14].

The preliminary analysis of prices and net trades (as difference between total awarded quantities on the demand and supply side) on the day-ahead, intra-day and balancing market sessions have been computed for all zones. The Northern zone of Italy is interestingly found to be in a persistent situation of "excess demand" after the closure of MGP market, without considering flows across national zones and foreign markets. In this situation, "up-regulating" power must be purchased during MSD and MB sessions. This is clearly explained by Figure 2, where the dynamics of day-ahead electricity zonal prices ("MGP price" in the top left panel), together with the weighted prices observed on the first intra-day market session ("MI1 price" in the top right panel) and with the weighted

[13] The reason is related to the changing price profile in MGP market, where the spread between peak and off-peak diminished, making this technology less profitable, see Gianfreda et al. (2018) for a detailed analysis.

[14] For this reason the data we use differ from prices computed and published by Terna for each ex-ante MSD sessions.

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MSD and MB prices (in both bottom left and right panels respectively) are represented with the corresponding net trades taking place at hour 11.

All together, we do not expect significant changes brought about by the introduction of RES generation at hour 3, because both demand and RES production are low (as well as imports). At hours 11 and 13, we expect a significant change brought about by RES-E, since demand is very high and RES generation is at its maximum (with the peak of solar production). Moreover, flows exhibit with similar intra-daily values over 2006 and 2013, with increments in 2014 but a dramatic drop in 2015 values to those observed in 2008; at the beginning of the financial crisis. At hour 19 we expect some changes because demand is still high, solar PV is low but wind is still contributing to the total generation. Furthermore, imports are at similar levels on both samples, and starting to increase only in 2015. At hour 21, hydro generation is around its maximum with wind contributing to generation, while demand is still high. And again, imports are at similar levels on both samples, but for 2015.

All together can explain the reduced influence of fuels on the dynamics of day-ahead electricity prices, but other elements might have changed this relationship on the balancing market. Hirth (2018) has disentangled the individual effects of different factors (like RES, decreasing gas and coal prices, demand reduction, market coupling and nuclear phase-out) on the reduction of German day-ahead prices over the sample 2008-15. RES are found to be by far the main responsible of this price decrease (half of a total 59% day-ahead price reduction). Starting from the same premises, we consider the dynamics of log-prices on both markets. And, we expect more relevant changes in day-ahead and a lower impact on balancing sessions, perhaps with various magnitudes at different hours. We also expect that, as thermal sources are gaining relevance as supplier of flexibility, balancing prices should be more related to fuel prices in the second sample.

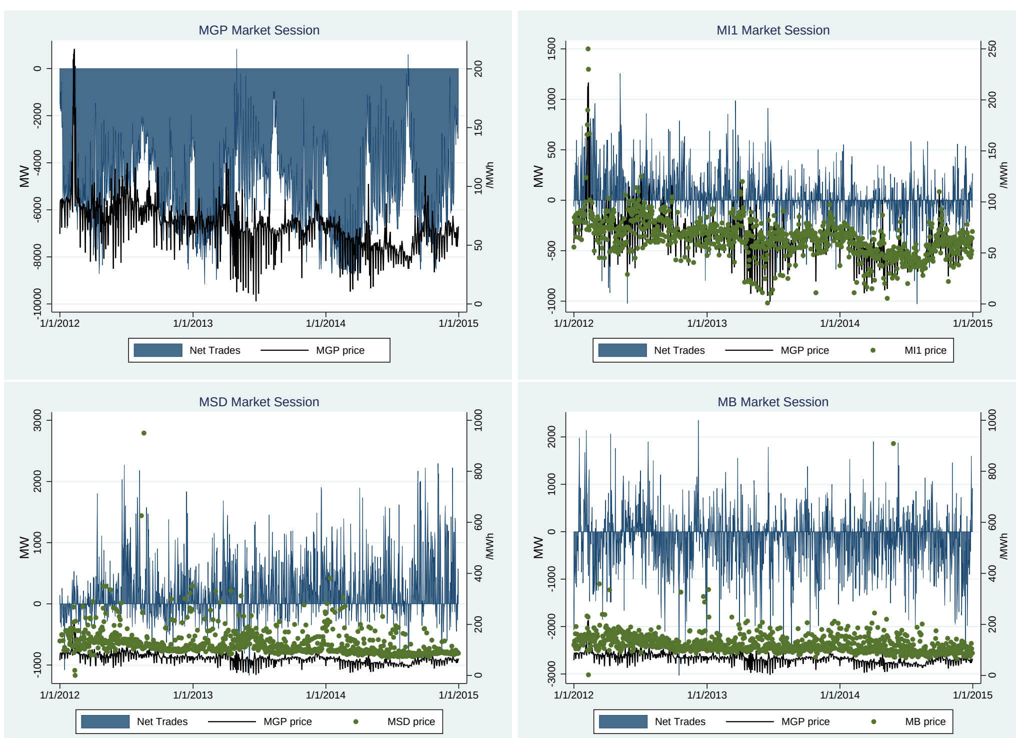

Figure 2: Net quantities during hour 11 in Northern Italy across MGP, MI, MSD and MB sessions respectively, together with corresponding weighted prices.

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4.2 Methods

We have pre-processed our time series to undertake the analysis by means of vector autoregressions (VAR), generally in the form of *vector error correction models* (VECM), and tools such as *forecast error variance decomposition* (FEVD) and *impulse response functions* (IRF), as described below.

It is a well known fact that wholesale electricity prices are very far from behaving like Gaussian processes (Bottazzi et al., 2005; Bosco et al., 2010) and, thus, least-squares based econometric methods tend to provide unreliable results. Furthermore, the data generating process of electricity prices can be viewed as the sum of a persistent component linked to the marginal costs of production and affected by the market structure plus an extremely noisy and leptokurtic component determined by short-term "shocks" such as strategies of the market participants, mismatch between the actual demand and its forecasts, plant maintenance, exceptional meteorological events, etc.[15]

Before analyzing the (Granger) causal relations between electricity and fuel prices, we need to clean the daily time series of electricity from components such as seasonal periodicities and additive outliers that are not present in fuel prices. In other analyses like Bosco et al. (2010) and Gianfreda et al. (2016b) we took care of these components by reducing the frequency of the time series using weekly means or medians, but since Italian electricity prices are heavily affected also by a 365-day periodic component and fuel prices may have also short-term effect on electricity prices, in this work we decided to keep all the time series at their original (daily) frequency and annihilate the components that could partially hide or alter the causal relationships between the time series. The data pre-processing[16] is conducted on the basis of the following steps.

1. Estimate the unobserved component model (UCM) $y_t = \mu_t + \gamma_t + \theta_t + \varepsilon_t$, where μ_t is as a random walk, γ_t is a time-varying periodic spline component with a 365-day period, θ_t is a time-varying trigonometric seasonal component with a 7-day period and ε_t is a white noise [17].
2. Identify all the additive outliers by using the auxiliary residuals relative to the observation error sequence ε_t.
3. Estimate the same UCM adding one dummy regressor for each additive outlier identified in the previous step (alternatively, the observations identified as outliers can be set to missing).
4. Compute the outlier- and seasonality-free time series as $\hat{y}_t = \hat{\mu}_{t|n} + \hat{\varepsilon}_{t|n}$, where $\hat{\mu}_{t|n}$ and $\hat{\varepsilon}_{t|n}$ are obtained by running the state smoother on the respective components using the UCM of the previous step.

All time series of the logarithm of electricity, coal and gas prices were tested for a unit root and stationarity using the ADF and KPSS tests over the full sample 2006-2015, and the conclusion is that all time series are integrated of order one (i.e., I(1)). Since our conjecture is that the strong increment of RES generation induced changes in the relation between electricity and fuel log-prices, all the following analyses have been carried out separately on the two subsamples.

We considered the vector of time series containing fuel log-prices and day-ahead log-prices and then the vector containing fuel log-prices and balancing log-prices. Each electricity log-price time series was added individually to the fuel log-price vector, so that the VAR/VECMs we estimated were always four-dimensional. For each subsample, we determined the order of the VAR using the Akaike (AIC) and the Hannan-Quinn (HQC) information criteria and tested for the order of cointegration using Johansen's sequential test. The results are summarized in Table 1. Notice that we report only one cointegration rank for each model because Johansen test selected always the same number of cointegrating relations under both AIC- and HQC-based VAR orders. The main message of Table

[15] In a pilot study about the behavior of the Dickey-Fuller and Johansen tests when data are generated by processes similar to the one observed in electricity price time series, the pre-filtering approach used in this paper seems to be the one that better preserves the size and power that these test have for Gaussian data.

[16] These computations were carried out using the PROC UCM of SAS/ETS. The code is available on request.

[17] See Harvey and Koopman (1993) and Pelagatti (2015).

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		Day Ahead			Balancing Market		
	Hour	Lags (AIC)	Lags (HQC)	Coint. Rank	Lags (AIC)	Lags (HQC)	Coint. Rank
First Sample	3	4	2	2	3	2	2
	9	3	2	2	3	3	2
	11	3	2	2	3	2	2
	13	3	3	2	3	2	2
	19	3	3	2	3	2	2
	21	2	2	2	3	2	2
Second Sample	3	3	3	1	3	1	1
	9	3	3	1	3	3	1
	11	6	3	1	3	3	1
	13	5	3	1	6	3	1
	19	6	3	1	6	3	1
	21	5	3	1	3	1	1

Table 1: Results of the lag-selection procedure and Johansen's cointegration test applied to the vector of time series containing the log-prices of gas, coal, oil and electricity.

1 is that the number of cointegrating relations reduced from 2 to 1 both for day-ahead log-prices and balancing log-prices. There is a long run equilibrium that keeps fuel prices and electricity prices aligned. A detailed analysis of the long run effects of unexpected shocks in fuel log-prices on electricity log-prices can be carried out observing the FEVD plots.[18]In order to better inquire the direct relationship between the balancing prices of thermal plants and single fuel prices, we estimated also bivariate VAR/VECM models for all the pairs you can form with the six log-price series and the three fuel series (18 models) and, then, produced the relative IRFs.

4.3 Empirical Results

Given that we want to analyze the impact of fuel prices on the dynamics of electricity prices in both day-ahead and balancing sessions, we have decomposed the forecast variance of electricity prices in terms of shares due to coal, oil and gas prices looking at specific hours of the day as specified above. In this way, we are able first to explore the evolution of the relationship between the prices of electricity and hydrocarbons, and secondly to establish the importance of these fuels in determining the electricity prices in the long run and under different market conditions. Considering a time horizon of 350 days, results from the FEVD for the Northern day-ahead and balancing prices are depicted respectively in Figures 3 and 4, with the left column devoted to the analysis on the first sample (2006-2008) and the right column devoted to the second one (2013-2015).

As we expected, the most striking results are obtained for the day-ahead market sessions where RES supply increased considerably in our second sample. In all hours we notice a strong reduction in the influence of gas prices in explaining the dynamic behavior of electricity prices. More generally, fuels maintain (and in peak-hours reinforce) their overall relevance in determining movements of day-ahead electricity prices, with significant shares of the forecast variance especially in the last years. However, we document a switching change between gas (leading the first sample) and coal (leading instead the second sample). We refer to this phenomenon as the *switching effect* among fuels. Our finding can be considered as one of the consequences brought about by the "merit order effect", already documented for other EU markets and the Italian MGP (in (Cló et al., 2015)). In particular, Hirth (2018) observes that the increasing RES (that are dispatched with priority) shifts the market supply on the right, changing the marginal technology. Since the marginal technology sets the equilibrium price, an increase in coal and a decrease in gas marginality, at least in some hours, may explain the results of our analysis, in which we observe coal increasing its influence on the dynamics of electricity prices. He shows that demand reduction had a much lower role with respect to RES penetration. Another element that should be considered as a potential explanation of our "switching" result is related to international market conditions for fuel prices. During our sample period, we

[18]Computations covered in this subsection have been carried out using the open-source econometric package Gretl.

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observed a situation of both low coal and gas prices (see Figure 8 in Appendix B), which however could have determined low electricity prices, but they could not have determined a merit order switch.

Looking at balancing prices and at their FEVD presented in Figure 4, we observe less pronounced changes. First, fuels maintain the same relevance in determining the dynamics of prices across the two samples, with slight increments again in peak hours over the sample 2013-2015. Although, they appear to be far less important with respect to day-ahead sessions: FEVDs indicate that more 60% of electricity prices variance is explained by unexpected shocks on fuels in the day-ahead market but only around 20-40% in balancing sessions. Secondly, we detect more fragmentation in the second sample with all fuels playing a role, whereas in the first sample only one or two out of three were leading the forecast variance. It is worth to observe that gas shares increased in the second sample especially during peak demand hours 11 and 13, and at the same time we assist to an increasing role of coal during ramp hours 9 and 21. The fact that the relative importance of gas on the forecast variance of balancing prices remain similar (or eroded to coal and oil) across the two samples, while gas substantially decreased/disappeared in the MGP, confirms the intuition of their evolving profit opportunities across market sessions. Since gas-fired plants lose a large share into the day-ahead market, they are forced to move towards balancing. Indeed, Gianfreda et al. (2018) observe that thermal units dramatically increased the maximum bid prices on the real time MB sessions, specially at hours 3 and 13, reaching the market cap price of 3000€/MWh only in the second sample. Instead, hydro was bidding the cap price at hours 11, 19 and 21. We also recall that RES units are allowed to participate in day-ahead session only. The fact that we observed relevant changes in day-ahead and not in balancing sessions supports out hypothesis that RES are the main responsible of the changes observed.

The low impact of fuels on balancing prices can be explained by many other important facts influencing the prices determined at real time[19], as the high concentration of this market segment where few units can exploit their dominant position. Therefore, it seems that balancing prices are more strategy-driven than cost-driven and this poses new and relevant policy questions about design of real time market sessions. Another reason that can explain the low influence of fuels on balancing prices is related to the structure of the generation industry in the North of Italy. As described in Section 3, units delivering balancing services in the considered zone are thermal, hydro and water pumping plants. Gianfreda et al. (2018) show that in the second sample the quantities supplied by water pumping were considerably reduced. Given that water pumping together with hydro units may hide or reduce the effect of fuel prices, in the following analysis we consider balancing prices determined from accepted bids awarded only to thermal units.

Hours	Fuels	2006-2008	2013-2015
3	coal	0	1
	gas	0	1
	oil	1	1
9	coal	1	0
	gas	0	1
	oil	1	1
11	coal	0	0
	gas	0	1
	oil	0	1
13	coal	1	1
	gas	0	1
	oil	0	1
19	coal	1	1
	gas	0	1
	oil	0	1
21	coal	0	1
	gas	0	1
	oil	0	1

Table 2: Number of cointegrating relations in the bivariate models when considering balancing prices (determined by thermal units only) and individual fuels.

We build 18 bivariate time series composed by the balancing prices determined by thermal units at each hour (3, 9, 11, 13, 19, 21) and a single fuel price (coal, gas, or oil) and we

[19] Among them, plant unavailability and forecasted errors (in both demand and supply) play a fundamental role, but we do not deliberately take into account because they go behind the scope of this investigation.

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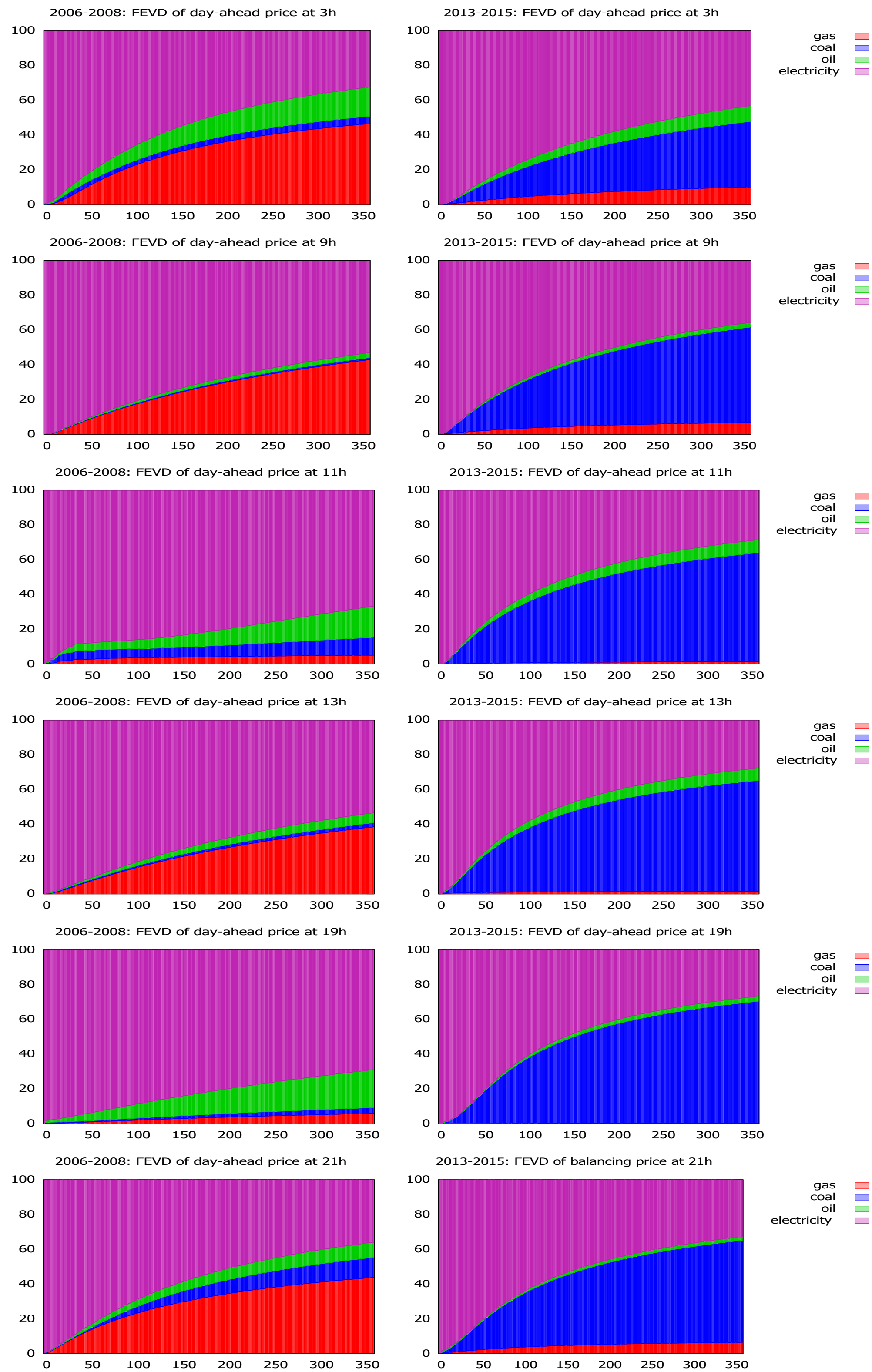

Figure 3: FEVDs for Northern Italian day-ahead prices: sample 2006-2008 on the left and 2013-2015 on the right.

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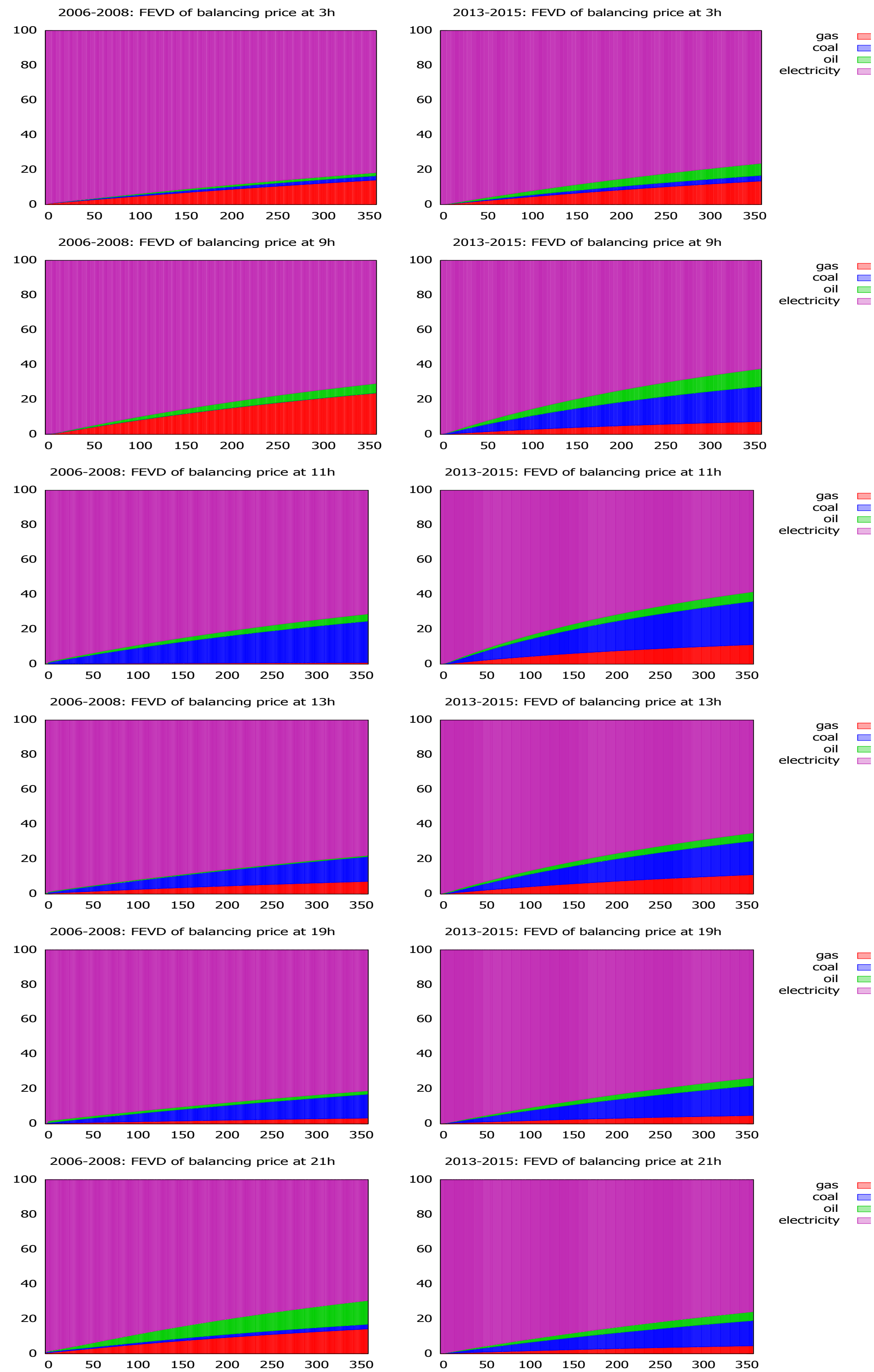

Figure 4: FEVDs for Northern Italian balancing prices: sample 2006-2008 on the left and 2013-2015 on the right.

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estimate the number of cointegrating relations using Johansen's procedure (with $\alpha = 0.05$). The results are summarized in Table 2. The main conclusion that one can draw is that the long run dependence between thermal balancing prices and fuels is much stronger in the second sample. In particular, if we consider gas, which is the most important fuel used by those units, there was no long run dependence (cointegration) in the first sample, while in the second sample balancing prices and gas share a common trend. This finding supports our initial hypothesis that the new scenario with increasing RES generation has enhanced the importance of fuel prices in the formation of balancing prices, at least in thermal segment.

As expected, in all the estimated rank-1 VECM the fuel resulted weekly exogenous, meaning that balancing prices adjust to fuel prices and not vice-versa. Figure 5 depicts the impulse response functions of 'thermal' balancing prices to a positive shock (of one standard deviation) in gas prices (with 90% confidence band based on bootstrapping). Of course, balancing prices increase as gas prices grow, but the strongest effects are observed at hours 9 and 11.

Going further, the estimated long-run elasticities of the balancing prices determined by thermal units to the fuel prices at selected hours are depicted in Figure 6, left panel. We include also day-ahead price elasticities (right panel) for comparison purposes. These elasticities are derived from the cointegration vector of the estimated VECM, as we modeled the logarithm of prices. Technically, the elasticities with respect to coal at hours 9 and 11 should not be there, since Johansen test did not reject the hypothesis of "no cointegration" for the pair balancing prices–coal prices at those hours (see Table 2). However, we report them anyway because they seem coherent with the other estimates and, because of the repeated testing, the probability of having made a couple of wrong decisions is not negligible. The long-run elasticities are significant in the morning hours, while they are virtually zero after hour 13.[20] But more importantly, we observe that coal prices seem to influence 'thermal' balancing prices more than gas prices, and that gas prices are more influential than oil prices. This result is consistent with our findings on the MGP, where we show how coal prices have increased their impact on electricity prices in the sample 2013-2015 (see Figure 3).

5. CONCLUSIONS

Despite the regulatory concerns and the attention paid in the recent "Winter package", balancing markets have not been analyzed in deep by the literature. In particular, there is lack of evidence on driving forces governing the behavior of balancing prices. At the same time, the sudden and increasing renewable power generation makes the relations among day-ahead and fuel prices highly questionable, at least in recent years.

Considering day-ahead and balancing electricity markets for the Northern Italy, we undertake our empirical analyses selecting specific hours on the basis of different load and RES production. This allows us to disentangle our results according to certain load levels and to highlight the influence of RES according to their intra-daily profiles. We consider two sample periods characterized by low (2006-08) and high (2013-15) RES penetration and we propose few hypotheses about the resulting dynamic relationship among fuels and electricity prices in both day-ahead and, for the first time, balancing markets.

Our findings firstly confirm that the increasing RES penetration has substantially changed the traditional relationship between electricity and fuels prices in day-ahead markets. In particular, we show that RES are able to reduce the role and the influence of fuels in the day-ahead sessions. We find that coal-fired power generation has increased its influence on electricity prices. We explain this result referring to the 'merit order effect' of RES: they not only contribute to a decrease in price

[20] According to Johansen test, we do find a long-run equilibrium between balancing prices and fuel prices also in the 13^{th}, 19^{th} and 21^{th} hours and this may seem contradictory with the values of the elasticities being almost zero. However, an insignificant significance test does imply that a coefficient is actually zero, but only that a zero coefficient is compatible with the observed data. Thus, we may interpret the two results (Johansen and t-test) as evidence of the presence of long-run equilibria with very small elasticities in certain hours.

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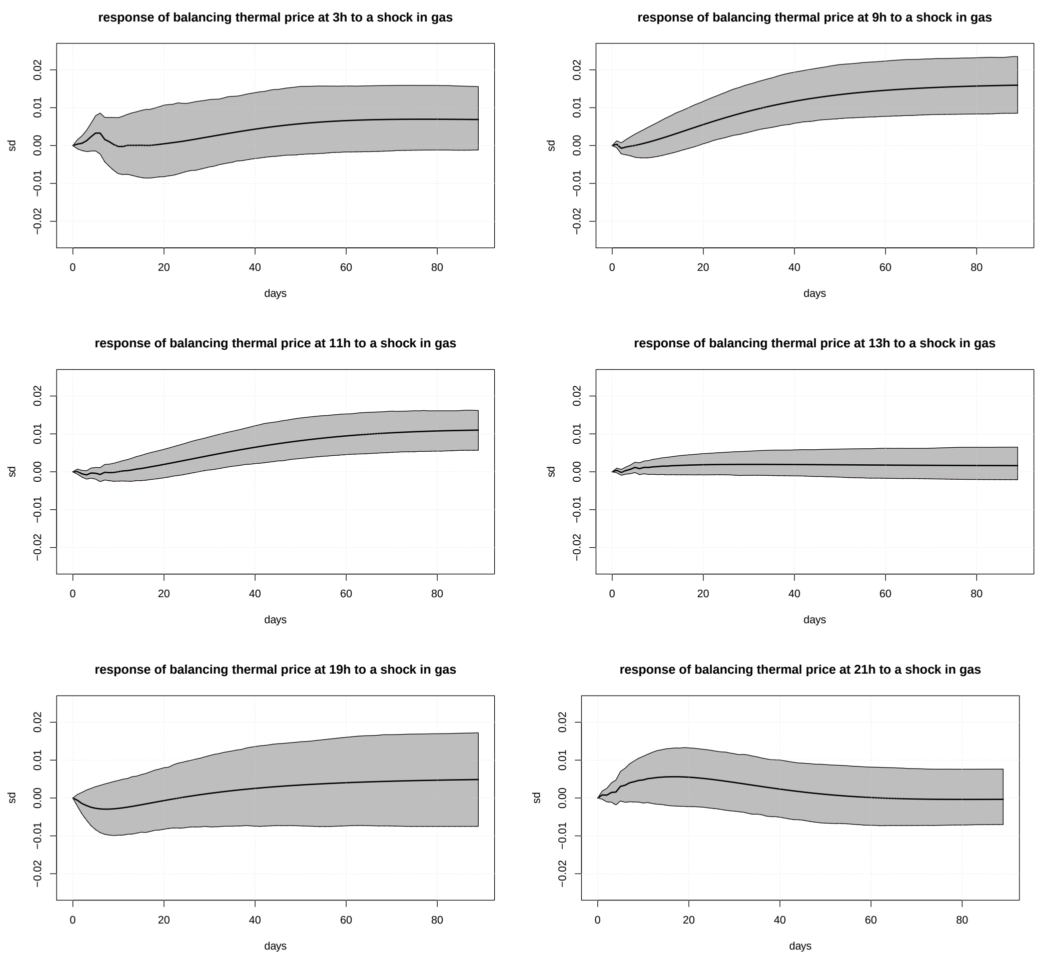

Figure 5: IRFs of balancing prices (determined by thermal units) at different hours of the day for a positive shock in gas prices.

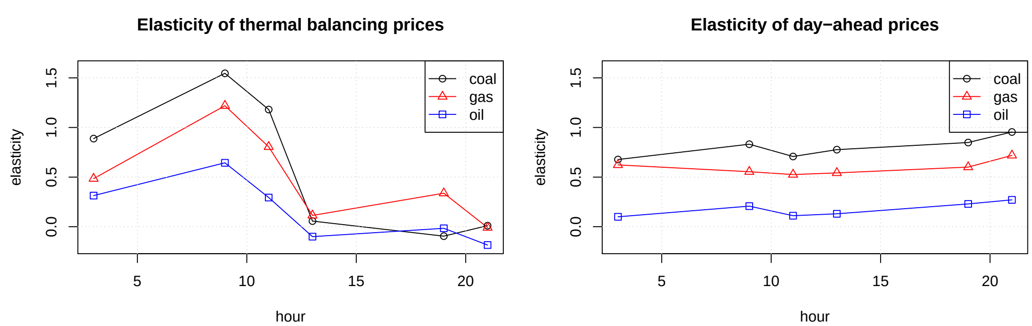

Figure 6: Elasticities of electricity prices to fuel prices at selected hours (2013-2015).

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level, but shifting the supply on the right they make more likely that coal becomes the marginal technology. This in turn explains why the dynamics of electricity prices is more likely to be governed by movements of coal prices in the second sample. Moreover, the switching from natural gas (the less emission-intensive generation source) to coal raises new challenging questions for policies aiming at reducing greenhouse gas emissions.

Another important point is related to how RES impact on the electricity system on costs and benefits perspective. This issue, strictly related to the analysis conducted in this paper, has been deeply analyzed in Gianfreda et al. (2018), where balancing costs for different technologies are estimated and compared across specific hours. While balancing quantities decreased even in the presence of increasing RES penetration, there is evidence of increasing balancing prices in particular market conditions, due to strategic use of real time sessions by conventional producers prone to the merit order effect in the day-ahead market. Increasing costs related to balancing activity must be added to subsidies received by RES producers and paid by consumers in the electricity bill.

Secondly and more importantly, we provide empirical evidence that fossil fuels are not relevant drivers of electricity prices in balancing sessions since they explain around 20% of the variance of electricity prices in a one-year time horizon. However, we show that in the second sample there is a common trend between balancing prices paid to thermal units and gas prices. This novel finding is interpreted as a signal of how firms respond to changing market opportunities. The high and sudden RES penetration has reshaped the competitive conditions in electricity market sessions, with gas units forced by RES to work less hours with respect to their break-even point in the day-ahead market (this is frequently known as the "curse of CCGT units") and therefore they revert to real time sessions where they still enjoy a leading role. As a result, flexible thermal units are restricted to bid in real time markets where they must recover both fixed and variable costs. This could explain why prices in balancing sessions are generally mildly cost-reflective and share the same dynamic behavior with the main fuel price, namely gas.

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APPENDIX A: SELECTION OF THE SUBSAMPLES

The selection of the two subsamples on which we conducted the cointegration analysis was originally based on qualitative arguments and previous literature. Indeed, we observed that in Italy a significant increase in the RES share of electricity production took place in the years 2009–2012 and, thus, we excluded this transition period from the analysis.

In order to support our choice with quantitative arguments, we tested for the constancy of the cointegration vector using the method proposed by Hansen and Johansen (1999). The test was applied to the logarithm of fuels and IPEX day-ahead prices first to the sub-sample 2006-2008 and then to the whole sample. IPEX prices are daily averages filtered as explained in Section 4.2. The Hansen and Johansen (1999) procedure is based on comparing the full sample and recursive estimates of the cointegration vector(s). Of course, the recursive estimates need a starting sample and, then, for every new time-observation the model is estimated again. From Figure 7, we see that while the constancy of the cointegration vector cannot be rejected for the subsample 2006-2008, if we consider the whole

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sample 2006-2015 and use 2006-2008 as starting sample, the constancy of the conitegration vector is rejected right from the first new observations (1 Jan 2009).

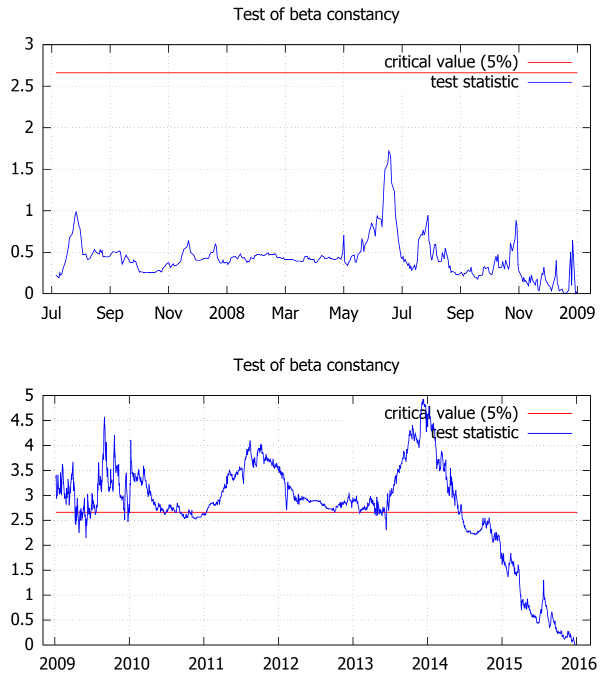

Figure 7: Hansen-Johansen test statistic for testing the constancy of the cointegration vector(s). Top graph: full sample is 2006-2008 and starting sample is Jan 2006 – Jun 2007. Bottom graph: full sample is 2006-2015 and starting sample is 2006-2008.

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APPENDIX B: REFERENCE FIGURES

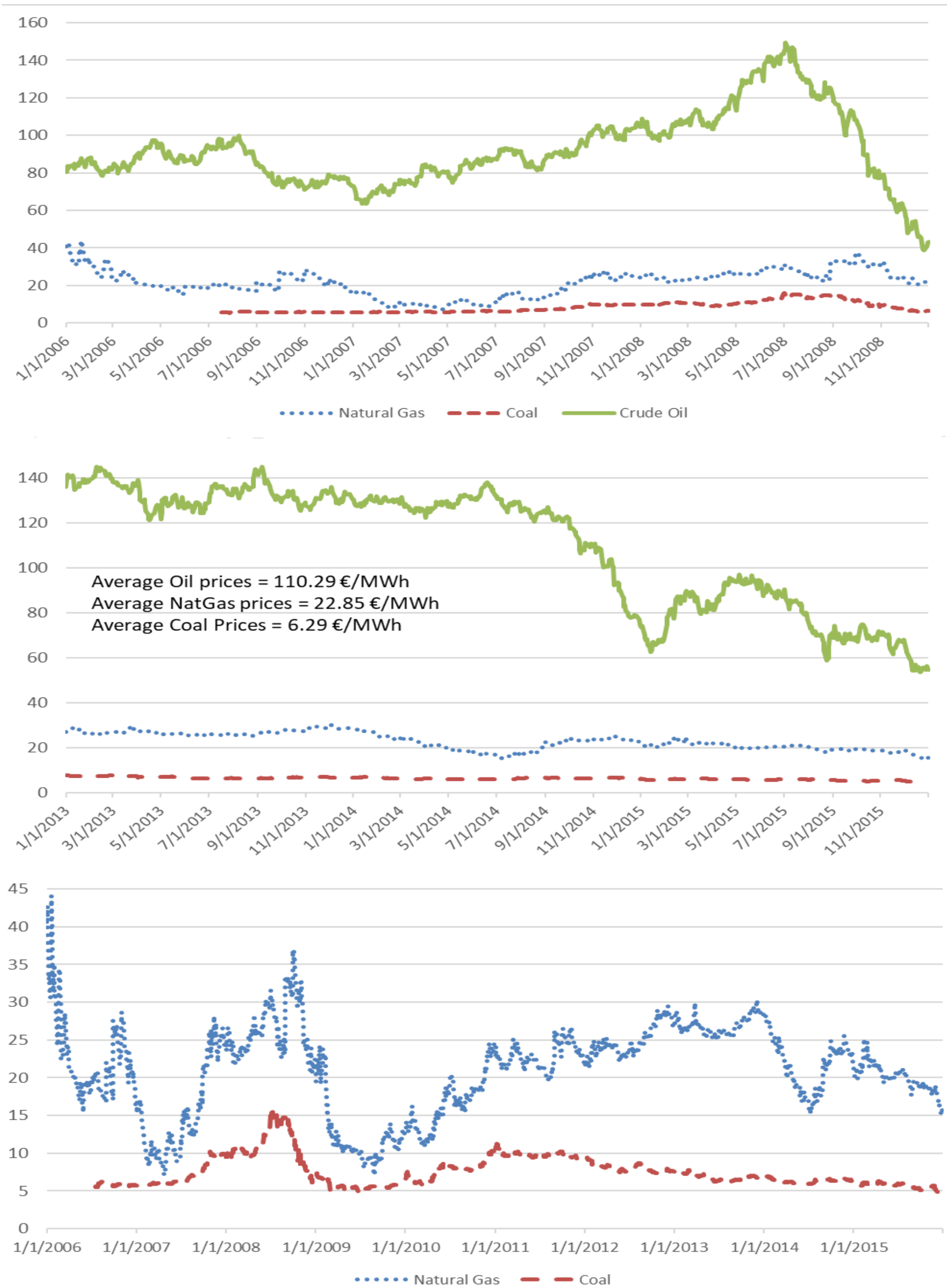

Figure 8: Price dynamics for Crude Oil, Natural Gas and Coal (all quoted in €/MWh) from 2006 to 2008 (on first row), on the second sample 2013-2015 (on the second row). Overall dynamics of Natural Gas and Coal prices over the full sample 2006-2015 are reported on the third row. Source data: Datastream

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