Economia Politica (2019) 36:527–548
https://doi.org/10.1007/s40888-018-0126-2

# Market coupling between electricity markets: theory and empirical evidence for the Italian–Slovenian interconnection

**Lucia Parisio**[1] · **Matteo Pelagatti**[1]

Received: 12 January 2017 / Accepted: 14 June 2018 / Published online: 25 June 2018


**Abstract**
Since January 1, 2011 the electricity exchanges of Italy and Slovenia are working under a mechanism of *market coupling* for their respective day-ahead sessions. Similar mechanisms are being implemented in many European countries to foster the integration of power markets that eventually will merge into one large European exchange. This paper is one of the first works in which, by analyzing market results, we try and assess the degree of integration of the Italian and Slovenian electricity markets due to the market coupling policy. Empirical results are useful to evaluate the success of the EU Price Coupling of Regions policy and suggest further enhancements.

**Keywords** Electricity markets · Market coupling · Cointegration · Robustness

**JEL Classification** L94 · C22 · C32

## 1 Introduction

The creation of a unique electricity market is at the core of European Union (EU) energy policy. It is considered a fundamental instrument to enhance competitiveness and to improve security of supply and sustainability of the whole industry.[1]

The integration of independent and often separated national markets can be obtained if two intermediate steps are accomplished: (1) increasing the amount of interconnecting lines that flow electricity cross-border and (2) implementing

[1] EU Directives 96/92/EC, 2003/54/EC and 2009/72/EC.

✉ Lucia Parisio
lucia.parisio@unimib.it

Matteo Pelagatti
matteo.pelagatti@unimib.it

1 DEMS, University of Milan-Bicocca, Milan, Italy

technical rules and allocation methods that use efficiently the available and future interconnection capacity.

Regulation 1228/2003/EC introduced some fundamental guidelines for the management of cross-borders flows. First, it stated the principle that cross-border capacity should be allocated in a transparent and non-discriminative way by means of market-based rules that convey the efficient set of signals and incentives to market participants and Transmission System Operators (TSO).[2] Second, transport capacity which is not used must be reallocated to the market according to the same principles outlined above. To insure a full usage of the capacity the netting of flows is encouraged. Third, the access price for the interconnecting lines should be harmonized and paid to TSOs on the basis of scarcity signals (demand-supply imbalances) more than on distance between the points of injection and withdrawal.

The new principles introduced by the above mentioned Regulation changed substantially the approach toward energy trade among EU countries. While in the past cross-border trade was considered an instrument to preserve safety of national systems in case of sudden faults, in the era of merit order allocations it becomes an instrument to promote effective competition at the EU wide level and to achieve market integration.

In the last decade, the EU Commission has worked for the creation of a common legislative framework to ease the establishment of the Internal Electricity market. The " Third Energy Package" issued in 2009 further enhanced the cooperation among national regulators and TSOs, and encouraged the establishment of permanent working groups with the aim of promoting harmonization.

The EU rules however did not indicate a specific market mechanism to allocate cross-border capacity and this left room for the flourishing of different regional initiatives implemented by national TSOs and regulators, with varying degrees of coordination. Therefore, progress towards electricity markets integration appeared to follow a bottom-up direction connecting areas and countries sharing similar concerns about energy exchanges. These regional groupings of regulators and TSOs are seen as platforms for the experimentation and development of new and efficient exchange procedures. At the same time, this bottom-up policy perspective has been complemented by a common EU policy towards the co-financing and construction of large energy infrastructure[3] according to the EU " Priority interconnection plan" of 2006. The mixing of regional initiatives with an EU-wide coordination plan should at the end promote the creation of one or more optimal energy exchange areas.

The Summer Package[4] issued by the European Commission in 2015 has set new electricity market rules to improve EU internal energy market integration. The new Regulation created a comprehensive and compulsory legal framework for electricity trading in Europe aiming at improving the functioning of internal electricity market. According to this, electricity flows should move in an economically efficient manner

[2] See also EU Commission 2009.

[3] These provisions are contained into Regulation n.347/2013 of the European Parliament

[4] "Regulation establishing a Guideline on Capacity Allocation and Congestion Management", entered into force on 15th August 2015

so as to maximize welfare and provide the right signals and incentives for investments, while fully integrating increasing shares of renewable energies.

To this end, different national power exchanges are required to share the set of bids submitted locally and to allow optimal matching of them across borders. To achieve the full integration goal, it is also necessary to remove barriers to electricity trade, coordinating grid operation through a series of new EU laws (known as 'network codes and guidelines') and involving TSOs. More cross-border trade will increase competition in electricity markets, and more coordinated system operation will save unnecessary costs resulting from the current fragmented grid operation.

The new Regulation on market coupling sets the basis for future better integration of electricity transaction in real time (Intra-day and Balancing sessions). This will allow for a more efficient integration of renewables into the market, as suppliers and traders can take into account better forecasts on how much solar or wind energy will be produced. Most importantly, the new rules have established a new framework for decision-making and regional cooperation amongst stakeholders: grid operators, power exchanges and regulators.

On 30 November 2016, the European Commission proposed a further package of measures (known as the Winter Package) including new rules on EU energy market design in order to ease the inclusion of supply from larger shares of renewables across the EU. The new regulation is prompted by the observation that, at the wholesale level, cross-border competition has generally increased but the system is far from achieving the full advantages of integration. In particular, electricity was observed not always flowing directly to where it is most needed, and some countries appears to be still reasoning on a purely national perspective, privileging internal security of supply, without taking account of the impact on neighboring countries. The new market rules include removing price-caps in wholesale markets, allowing better price responsiveness and scarcity signaling, removing priority dispatch for large scale renewable generators, reinvesting cross-border revenues into grid expansions to remove further bottlenecks and promoting closer coordination among TSOs.

In this paper we analyze one of the coupling experiences implemented on the basis of the above mentioned regulations. Starting from the beginning of 2011 Italian (GME) and Slovenian (BSP) day-ahead markets implicitly allocate cross-border transport rights of electricity. We use cointegration analysis applied to price series determined in the PXs, before and after the implementation, to evaluate the performance of market coupling towards price convergence and hence market integration.

In the next Section we describe the different market methods to promote integration and their performance in the efficient use of the available cross-border capacity. We also discuss the theoretical and applied literature in the field. In Sect. 3 we analyze our dataset for the sample period 2010–2013 and we present the main characteristics of the two coupled markets. Section 4 contains the long-run analysis of the two time series of prices, looking for some form of convergence which is evaluated using outlier-robust econometric techniques. A final section concludes.

## 2 Interconnection methods

There are different market methods available for allocating interconnection capacity: market institutions established across borders may have a low degree of involvement, limited to the sharing of information and data, while preserving their independence of operations, or they can implement an extreme form of harmonization. In this case one single "transnational" PX can be established to coordinate energy production and exchange for all involved countries. The literature[5] classifies possible interconnection agreements among these two extremes, according to the different degrees of cooperation required among national TSOs and/or power exchanges.

The explicit auction mechanism was one of the first method implemented to achieve integration between existing local markets; its main advantage is that it requires a low degree of coordination among TSOs. Segments of capacity in the opposite directions are allocated in a multi-unit auction. Each TSO announces the available capacity ex ante and allocates it accepting bids according to their price, until no free capacity remains. Each TSOs acts independently on one flow direction. In this way, capacity is allocated apart from the energy to be transmitted; physical energy is sold either through bilateral contracts or in (local) Power Exchange. We find examples of explicit auctions conducted by national TSOs, jointly or independently in the two different directions, with or without reserve price. Explicit auctions have been criticized[6] for not being efficient, particularly in the presence of meshed networks (networks normally operated with a number of parallel flow paths). More generally, explicit auctions are suitable for the case in which operators have signed physical long term contracts in a foreign country and consequently need the capacity to transport energy in the country of delivery. The management of explicit auctions is successful when there exists some form of coordinated action and exchange of information between TSOs.

National ad hoc cross-border agreements supported the implementation of coordinated explicit auctions. On October 1, 2008 a new common market platform, CASC-CWE, has been created by the five countries of the Central-West EU region. On November 10, 2010, the TSOs of Central-South countries and Switzerland officially joined CASC-CWE S.A. which becomes CASC.EU S.A. Since April 1, 2011 CASC.EU operates the explicit auctions on behalf of national TSOs on the shared borders of a large region of the EU. To this end, TSOs committed to a close cooperation to ensure reliable operation, optimal management and the best technical evolution of the system. Products auctioned on CASC-EU platform are physical transmission rights for different time duration: year, month, day and infra-day. Auction rules are common for all borders and products. Transmission rights are allocated on the basis of a merit order and paid under a uniform price rule. Pro-quota rationing is applied for identical bids received at the margin. Different products are allocated in

[5] Creti et al. (2010) present a table with a classification and examples of possible cross-border interactions.

[6] See Glachant (2010) and Chao and Peck (1996). Ehrenmann and Smeers (2005) evaluate various approaches to congestion management in the EU.

separated auctions and resale is possible only for a subset of them. The nomination is managed by local TSOs and yearly and monthly allocations can be re-auctioned in the auction for daily capacity. Daily and infra-daily capacities are subjected to the use-it-or-lose-it principle. Finally, the coordinated explicit auction mechanism requires a joint cross-border congestion management by TSOs and therefore the creation of a single point of operation, where the same Information Technology (IT) tools and harmonized rules are used.

A second market-based method is known as the implicit auction mechanism. In implicit auctions, the available capacity is allocated simultaneously with the physical energy in the domestic markets. The electricity bought is charged at the equilibrium price prevailing in the local market, whereas the use of cross-border capacity is remunerated by the difference between the two prices realized in each interconnected market. TSOs retain this price difference as compensation for the intermediation activity after netting, i.e. once the opposite flows are taken into account and compensated for. This allocation procedure has been first implemented by Nordic countries since 1993. In multi-national electricity markets each market is considered a zone and the implementation of the implicit auction mechanism can be done according to different alternatives.

There are three models of implicit auctioning implemented in the EU area: market splitting and market coupling (with volume and price coupling). The Nordic countries (Sweden, Finland, Denmark, Norway and more recently Estonia) adopt market splitting which is recognized to realize the strongest degree of integration among countries. In fact, one single power exchange is established (acting on behalf of local TSOs) that clears the market and sets the quantities. The market may split itself in different pricing zones when transmission constraints arise.[7]

The second model is represented by market coupling, where each country retain its national PX, so that the degree of integration is lower with respect to market splitting. PXs coordinate themselves through a common coupling algorithm, but they retain the pricing authority and may have different matching rules. There are two types of market coupling: volume coupling and price coupling. Netherlands, Belgium and France introduced a price coupling of their national PXs based on a common pricing algorithm governing the clearing of prices among the three regional markets. With volume coupling, adopted between Germany and Denmark, the central algorithm calculates cross-border flows, that are used by the national PXs to clear the local markets and set the prices.

Summing up, we observe that countries have adopted different solutions to the interconnection problem, either including other countries in the operation of a central PX or simply coordinating pre-existing trading platforms. In the second case, the participants of the individual PXs follow their local bidding procedures and national PXs maintain their market designs.

[7] Cooperation between a group of northern EU members begun in 1963 with the creation of Nordel organization. Since then, a long tradition of energy exchange, particularly between Sweden and Norway, was eased by the presence of a relatively high capacity interconnector.

The maintaining of national rules and independence are the reasons why market coupling is considered a good compromise to achieve integration while preserving possible local peculiarities. Therefore, the implicit auction in the form of " market coupling" soon emerged as the most recommended method for managing cross-border congestion. Market coupling is based on the assumption that an administered day-ahead market exists in each region (i.e. at each node of the simplified transmission model). Subject to the ability of the transmission model to support the associated flows, market coupling enables the regional markets to trade with each other if it is economically efficient to do so. A number of processes are necessary to support the day-ahead markets, for example by supplying data and providing financial settlement services and, moreover, some measures of short-term energy balancing are also required. The key advantage of market coupling is flow-netting for energy flows scheduled in the opposite directions. Since flows in opposite direction cancel, the line can be used up to full capacity. Therefore under market coupling imperfect arbitrage, which is a quite common attribute of explicit auctions, can be easily avoided and this results in an efficient use of the infrastructure.

On a policy perspective, the first approach followed by the EU to foster electricity market integration is know as Price Coupling of Regions (PCR)[8] with the objective of building a common pricing mechanism to coordinate power exchanges acting in a decentralized network.

Between November 2006 and November 2010, the EPEX SPOT French auction has been involved in the Tri-Lateral Market Coupling (TLC), integrating the French, Belgium and Dutch day-ahead markets. The next step of market harmonization was achieved on 9 November 2010, with the launch of market coupling in Central West Europe (covering Benelux, France and Germany), known as CWE. In parallel, CWE has been volume coupled since November 2010 with the Nordic region.[9]

On 4 February 2014, Price Coupling in North Western Europe (NWE) went live. It was the first initiative to use the pan-European PCR solution for the calculation of prices and flows - the starting point for all other regions to join. At the time of the launch, NWE stretched from France to Finland and from Great Britain to German/Austria, covering the region of CWE, Great Britain, the Nordics and the Baltics.

Since the launch of NWE, two extensions of the PCR-coupled area have taken place: in May 2014, Spain and Portugal joined; in February 2015, Italy coupled with France, Austria and Slovenia. As a result, the now-coupled area is called Multi-Regional Coupling and covers now 19 countries, standing for about 85% of European power consumption.

[8] The Project is operated by seven Power Exchanges and joins the following countries: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and UK. The initiative started in 2009 and the PCR parties signed Cooperation Agreement in June 2012.

[9] In May 2015, the calculation of cross-border capacities in CWE has switched to a more efficient process called flow-based methodology.

Soon as coupling exercises have been implemented across Europe, economic literature started to analyze theoretical properties[10] and performance of PCR projects through different empirical approaches. Some papers consider the Italian case. In a policy oriented paper, Creti et al. (2010) recognize the inefficiency of explicit auctions and explain the reasons why volume coupling should be the best option to increase interconnection among Italy and the neighboring countries. Italian PX rules show some peculiarities such as domestic market splitting rules, the absence of block orders and finally a different pricing rule for buying and selling,[11] which may prevent perfect integration. However, the paper does not contain empirical exercises since market coupling was not implemented yet. Glachant (2010) also suggests that PCR is the easiest way to achieve a better integration especially for those countries, like Italy, which are characterized by peculiar features in the wholesale market organization. The Italian case is also analyzed by Zani et al. (2012) who present a simulation exercise with and without coupling, showing that pricing and welfare results depend upon gas prices that were on average higher in Italy than abroad. Notwithstanding this, coupling is shown to reduce net imports and, most importantly, adverse flows enhancing efficiency.

Using simulative methods Ochoa and van Ackere (2015) analyze two coupling cases (one in EU, between UK and France, one outside EU, between Colombia and Ecuador) finding that the success of a coupling project depends upon the degree of complementarity among interconnected countries. Investments levels and storage capacity may influence coupling results and the resulting welfare redistribution.

More recently, three papers (Keppler et al. 2016; Kiesel and Kusterman 2016; Koban 2017) analyze specific coupling cases for the French–German and for the Hungarian–Romanian interconnections. Keppler et al. (2016) estimate the effect of coupling on prices spreads between France and Germany. They show that the implementation of a coordinated order book since 2010 has reduced price divergence. At the same time however, electricity production with renewable technologies, wind and solar PV in particular, is found to increase price spreads among the two countries. Authors conclude that the significant increase in the production of variable renewables that Europe has witnessed in recent years has modified the fundamentals of electricity trade and requires a new look at European power market integration. The same kind of results have been provided by Gianfreda et al. (2016b) for the major EU power exchanges.

Evidence from Nordic markets contrasts with that obtained for other European experiences. Early empirical studies on continental markets (Zachmann 2008) found them to be not well integrated, whereas few years later Bosco et al. (2010), using a robust multivariate long-run dynamic analysis, reveal the presence of four highly integrated central European markets (France, Germany, the Netherlands and Austria).

[10] Parisio and Bosco (2008) analyze the allocation properties of coupling methods with particular reference to implicit auctions.

[11] The buyers at PX pay the unique national price which is the weighted average of zonal prices in case of congestions. Sellers receive the zonal price.

In this paper we analyze the market coupling experiment between Italian and Slovenian day-ahead markets. In the next section we will describe how market coupling has been implemented and then we empirically analyze the dynamics of the two price time series in order to determine to what extent the market coupling mechanism has been successfully in achieving the integration of the two electricity markets expected by the European regulators.

## 3 The coupling between Italy and Slovenia

Since January 1, 2011 the electricity day-ahead markets of Italy (GME) and Slovenia (BSP) allocate the cross-border transmission capacity by means of an *implicit auction* mechanism. The *market coupling* implemented is a decentralized mechanism jointly managed by the two operators who share a common matching algorithm. Post-coupling activities like settlements, nomination and determination of the congestion rents are solved locally.

The Italian–Slovenian implicit auction mechanism is scheduled as follows:

1. the market participants submit their offers to the two day-ahead markets,
2. the two grid operators (Terna and Eles) communicate the available transmission capacity (ATC) for each hour of the next day,
3. the two markets share their information about the anonymous offers involving the use of the ATC,
4. the two exchanges compute the equilibrium prices and quantities,
5. if the capacity constraints are respected only one common price is formed, otherwise the two markets are split and a stream of energy compatible with the constraint is guaranteed to the country with higher equilibrium price.

The new mechanism complements explicit auctions for the allocation of transfer rights on interconnection lines joining the two countries. Explicit auctions, which require a separate allocation of transmission rights and physical energy, are still managed by CASC-EU for yearly and monthly products. Daily cross-border capacity is allocated simultaneously with electricity when the coupled interconnected markets clear. Under this design imperfect arbitrage cannot occur as energy always flows towards the high price country. Moreover, flows-netting implies that flows scheduled in the opposite directions cancel out, so allowing the efficient use of the inter-connector.

The implementation of market coupling requires a preliminary harmonization activity between the power exchanges involved. In particular, coupled markets should share the same timetable for bidding and computing activities and have compatible bid formats.

The Italian–Slovenian (IT–SL) market coupling experiment has been considered very important for its peculiar characteristics: on the Italian side, we have a quite large and liquid market characterized by the presence of generating units having high variable costs, whereas on the Slovenian side we have a comparatively smaller market (registering regular transactions since June 2010) with very limited capacity and a different fuel mix.

In particular, the total installed capacity in Italy[12] amounts at 106 GW whereas Slovenian capacity is equal to 3 GW only. The Italian electricity generation has undergone significant changes in the past years. On the one hand, the worldwide economic crisis hit aggregate demand and industrial production and consequently, electricity demand severely reduced from 330 TWh in 2005 to 320 in 2009 and to 308 in 2014 (consumption data by ENTSO-E).

More recently, policies aimed at accomplishing the 20-20 EU target resulted in effective support for new generation capacity based on renewables. The result of these generous subsidy schemes, together with the priority dispatch of RES generation in the day-ahead market, reshaped the aggregate supply function, pushing gas-fired plants and in particular, CCGT technology to the far borders of the market. More precisely, from 2010 to the end of 2013, the amount of electricity produced by CCGT plants dropped by 38% (− 27.7% if we consider production from all conventional sources). During the same period, generation from RES grew from 59.5 to 91.4 TWh (53.6%), with a stable share of hydro production, which is mainly concentrated in the North zone. Among renewables, wind and solar registered the most relevant result with an increase of 151 and 304%. In 2013, Italy was the third largest (second largest in the EU) country for PV capacity installed, following Germany and China. The main domestic energy sources in the Slovenian market are nuclear with a 22.5% share, coal with a 16.7% share, and, among renewables, hydroenergy with a 4.3% share, wood biomass and other renewable energy sources with an 8.8%.

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.[13] Slovenia is connected to the North zone of the Italian market.

The integration of a large market with a small one poses a number of interesting questions to be investigated. A first question is related to how the two markets interact in forming the clearing prices. Perfect integration requires a unique equilibrium price whereas partial integration entails some form of common dynamic of the two price series. A second question is related to the effect of interconnection on the bidding strategies followed by non-atomistic players in one or both markets. In this paper we pursue the first line of research while we leave the second to future work. In particular it will be interesting to analyze how the coupling experience has influenced the supply schedules of bidders on the importing side and the effect on marginal technologies.

[12] Details about the Italian electricity industry are presented in Gianfreda et al. (2016a).

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

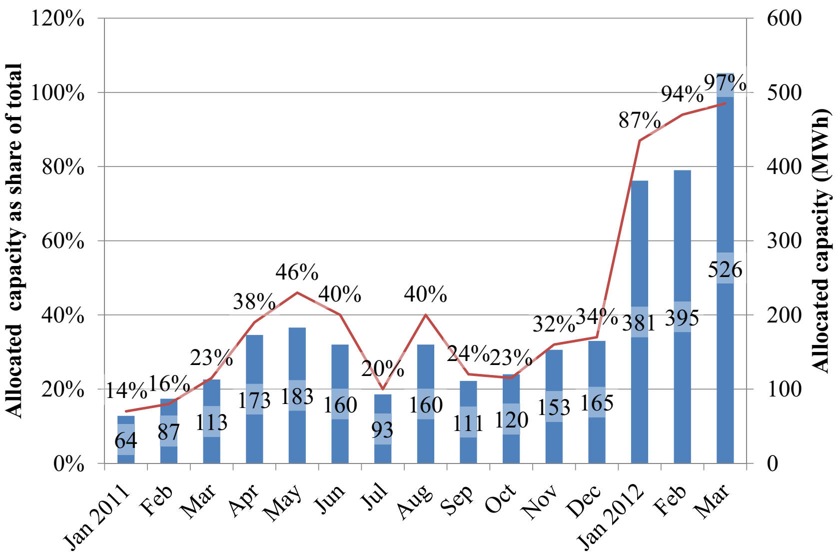


**Fig. 1** Interconnection capacity IT–SL allocated by market coupling

The IT–SL market coupling is considered a very positive experience. A first reason of success is recognized to be the attraction of higher volumes than those prevailing before coupling. The average capacity initially available on the It-SL border was equal to 465 MW. At the beginning of the coupling experience only 35 MW were allocated in the foreign BSP zone integrated in the Italian market, whereas the other portion of capacity was still allocated through daily explicit auctions. After 1 year of implementation of the new mechanism and due to the expiring of previously signed import contracts, the allocated capacity grew substantially to 165 MW and then to 526 MW in the Spring 2012, i.e. to 97% of total available capacity.[14] Figure 1 illustrates the evolution of the figures about market coupling.

The above mentioned result is a clear signal of the approval granted by market participants to this new allocation mechanism. Another indirect proof of the success of IT–SL coupling is the increase in the liquidity registered on the Slovenian exchange which grew from 0.2 TWh in 2010 to 1.5 TWh in 2011 and to 4.4 TWh in 2012. This success is partly explained by the massive use of the use-it-or-sell-it clause by participants: market agents may resell to the TSO the import capacity bought in advance (yearly and monthly allocations) and then buy it back on the Slovenian exchange by placing sale offers.

A second evidence of success of the new coupling mechanism is the improved efficiency in the use of the interconnection infrastructure: the system is able to allocate at all hours the transit capacity in the direction consistent with the price spread.

[14] The share of capacity allocated through the market coupling mechanism was stable at 95 % in 2012.

Moreover the full usage is guaranteed every time there is a positive differential.[15] Congestion rents, defined as the price difference times energy flowing from the high price to the low price area, are thus fully exploited.

A third reason of success is recognized in the ability of the coupling mechanism to promote a progressive convergence of prices between the two wholesale markets. While full convergence has not been achieved yet, still we notice a narrow price gap as the volume allocated through market coupling has increased.

## 4 Empirical analysis

### 4.1 Data

In this section we analyze the effect of coupling on clearing prices of the two day-ahead-markets; price formed in the Slovenian market, run by BSP, and clearing prices determined in the North Zone of the Italian day-ahead market, run by GME. We look for some form of convergence of the two series emerging after the activation of the market coupling mechanism. The Slovenian electricity market manager BSP granted us access to its database which consists of three types of files: (1) price curves tables that contain the anonymous bids and offers for every auction since 2011-01-01, (2) market result tables that list equilibrium prices and quantities for every auction since 2010-06-01 and (3) market coupling tables which contain the equilibrium prices in the BSP and in the North Zone of the GME, the offered capacities of Terna and Eles for the lines interconnecting the two countries and the allocated quantities on those lines since 2011-01-01.

While Italian prices are available on a regular basis since April 2004, data on equilibrium prices for Slovenia are irregular until June 2010. The Italian series is therefore longer than its Slovenian counterpart. In fact, the Slovenian market operator Borzen was established on 28 March 2001 but the market was very illiquid in its first years of operation. In 2005 for example, only 0.3% of the electricity consumed was traded on Borzen.[16] The 99.7% of the consumed electricity was exchanged through bilateral contracts lasting from 1 to 5 years. It was only with the expiring of these long term contracts that the power exchange started to be more liquid (11% in 2011).

By observing the plot of the daily MWh of electricity exchanged in the BSP in Fig. 2, it is striking how these quantities have radically increased from 2010-06-01 to 2013-12-31, with an upward jump at the beginning of 2011. Beside the quantity level also the volatility had an important increase.

Interestingly, the daily average price prevailing in the BSP day-ahead market appeared to be not influenced by the increase in the exchanged quantity (cf. Fig. 3).

[15] In 2011 the flows resulting from market coupling were 100% efficient.

[16] Activities connected with energy exchange were under the responsibility of Borzen until November 2008, when responsibility was passed to the newly established company BSP Regional Energy Exchange, which was founded by Borzen and Eurex, the international derivatives exchange.

**Table 1** Descriptive statistics for GME and BSP prices computed on the last 5137 hourly observations (from June 1 to December 31) of each year

| Price | Mean | Median | Min | Max | St.Dev. | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| 2010 (from June) | | | | | | | |
| GME | 63.7 | 63.8 | 10.0 | 189.0 | 17.5 | 1.0 | 4.3 |
| BSP | 48.2 | 48.2 | 4.8 | 117.0 | 13.7 | 0.1 | 0.6 |
| GME − BSP | 15.5 | 13.7 | − 13.2 | 139.6 | 13.5 | 1.7 | 6.8 |
| GME > BSP | 91.1% | | | | | | |
| GME = BSP | 0.0% | | | | | | |
| GME < BSP | 8.9% | | | | | | |
| COR (GME, BSP) | 0.65 | | | | | | |
| 2011 (from June) | | | | | | | |
| GME | 73.3 | 72.3 | 15.0 | 165.1 | 16.6 | 0.8 | 3.2 |
| BSP | 59.6 | 57.1 | 1.0 | 165.0 | 20.3 | 0.6 | 1.2 |
| GME − BSP | 13.7 | 12.1 | − 5.0 | 84.4 | 13.1 | 1.0 | 1.3 |
| GME > BSP | 73.1% | | | | | | |
| GME = BSP | 26.8% | | | | | | |
| GME < BSP | 0.1% | | | | | | |
| COR (GME, BSP) | 0.77 | | | | | | |
| 2012 (from June) | | | | | | | |
| GME | 72.5 | 72.8 | 16.8 | 155.0 | 18.8 | 0.2 | 1.3 |
| BSP | 49.4 | 48.3 | 0.0 | 150.0 | 20.8 | 0.3 | 0.3 |
| GME − BSP | 23.1 | 21.5 | − 8.4 | 108.5 | 17.3 | 0.7 | 0.6 |
| GME > BSP | 88.6% | | | | | | |
| GME = BSP | 11.4% | | | | | | |
| GME < BSP | 0.0% | | | | | | |
| COR (GME, BSP) | 0.62 | | | | | | |
| 2013 (from June) | | | | | | | |
| GME | 62.2 | 63.0 | 0.0 | 150.0 | 16.2 | − 0.1 | 3.3 |
| BSP | 45.8 | 45.1 | 0.0 | 123.1 | 17.9 | 0.2 | − 0.2 |
| GME − BSP | 16.4 | 15.4 | − 35.1 | 125.1 | 13.7 | 0.7 | 1.4 |
| GME > BSP | 82.4% | | | | | | |
| GME = BSP | 16.5% | | | | | | |
| GME < BSP | 1.1% | | | | | | |
| COR(GME, BSP) | 0.68 | | | | | | |

From Table 1 we see an increase of the average Slovenian prices taking place in 2011 only, whereas this increase has been absorbed in the next 2 years. The Italian mean prices have been always higher with a peak of 23 Euro difference in 2012. However, the figures in 2013 are very close to those registered in 2010.

We also notice from Table 1 that the effect of the coupling experience was to foster price convergence in the two countries even if the share of hours in which the same price occurs are declining through sample years (26.8% of hours in 2011,

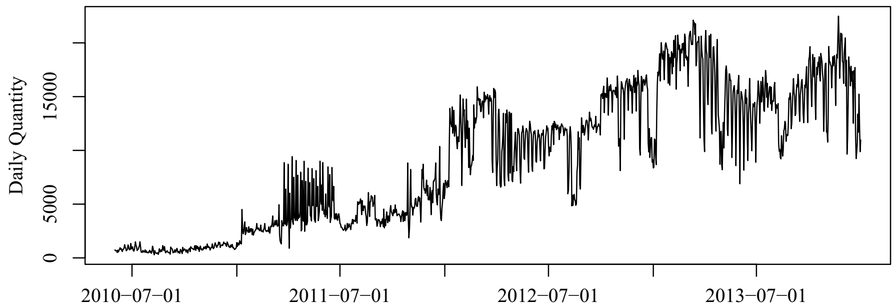


**Fig. 2** Daily quantities exchanged on the BSP day ahead market

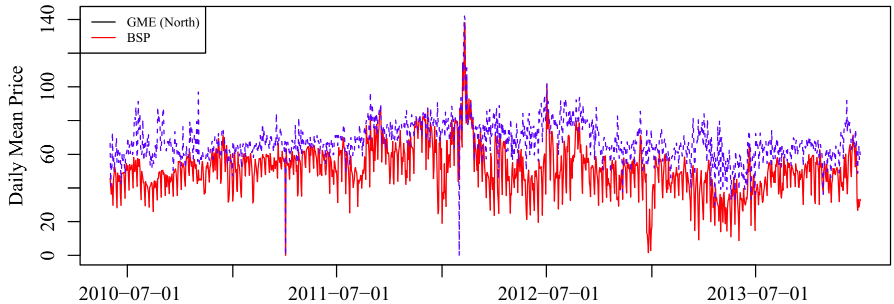


**Fig. 3** Daily mean prices on the Slovenian and Italian day ahead markets

11.4% in 2012 and 16.5% in 2013). Our hypothesis is therefore that a common dynamics between price series may be obtained thanks to the market coupling but perfect convergence is still far to be achieved. Using the terminology of De Vany and Walls (1999) we guess that *perfect integration* (i.e., zero intercept and unitary coefficient in the cointegration regression) between the two markets did not occur during our sample period but only a *strong integration* (i.e., non-zero intercept and unitary coefficient in the cointegration regression) characterized by a common long-term dynamics between price series, as also the higher level of correlation between prices suggests (the correlation computed over the entire period 2010–2013 is 0.71).

Price convergence in a quite significant number of hours can be explained on the basis of many causes that mainly concerned the Italian market. In particular, the economic crisis significantly reduced electricity demand in Italy (− 9.4% during our sample period) and, as a consequence, equilibrium prices in the wholesale market experienced a downward trend. In 2013 the equilibrium price (PUN) in the Italian spot exchange reached its minimum level since year 2006 with a significant drop of − 16.6% between years 2012 and 2013. A second relevant issue which may explain price reduction in the Italian market is the introduction of high shares of production from renewable sources (RES). During our sample period RES production

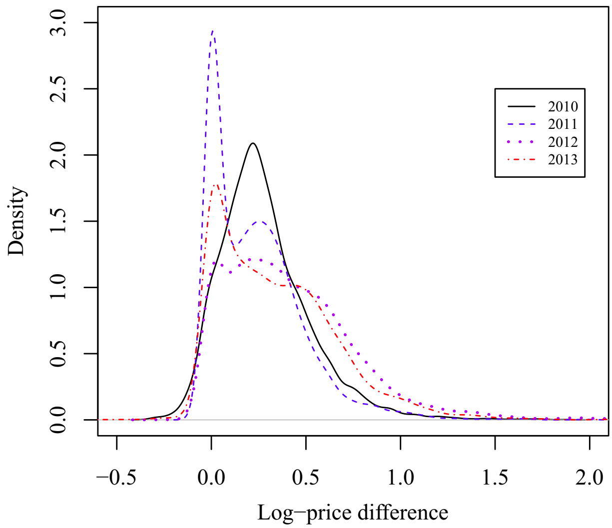


**Fig. 4** Densities of the difference between GME log-prices and BSP log-prices since June

increased[17] from a share of 3.8% in 2010 to 14.1% in 2013. Two main consequences are related to this: first, the aggregate supply function in the market shifted to the right so pushing out of the merit order conventional generators. Combined-cycle gas turbine (CCGT) plants became marginal not only in off-peak but even in peak hours (in 2013, in 44% of peak-hours, CCGT plants were price setters in the North zone). The second consequence which may be related to the introduction of RES production, solar in particular, is the change in the shape of the daily price series which now is more flat, i.e. there is less difference between peak and off-peak prices. Solar irradiation in fact allows production from this source at day-time whereas it leaves the place to conventional production at sunset. This contributed to a decrease in the equilibrium price during the day and in an increase of it in the evening. Finally we observe that in many hours of 2013 the equilibrium price has been fixed by foreign operators in a share of hours equal to 14.5%.

All these new features characterizing the Italian market suggest to us to analyze when price convergence occurred, looking at how the realizations of the unique price are distributed across hours and days of the week. An uneven distribution of realizations might suggest that other factors have helped convergence of the two coupled markets.

Interestingly the realizations of price convergence occurred at similar rates both at day and night times. In particular we calculate that an average 3.2% of occurrences are at night hours and an average of 5.3% are at day time. The maximum share of realizations of the unique price is registered for 1, 2 and 3 p.m. (respectively 7.3, 7.4 and 6.1%). Looking at how the realizations of price convergence occurred

[17] Data are taken from the Italian market operator website: http://www.mercatolettrico.org.

**Table 2** Stationarity tests for Slovenian and Italian prices

| | BSP | GME | Diff |
|---|---|---|---|
| Hourly data | | | |
| KPSS | 16.422 | 12.24 | 10.846 |
| Rank KPSS | 18.711 | 14.846 | 12.936 |
| Daily averages | | | |
| KPSS | 2.534 | 2.084 | 2.038 |
| Rank KPSS | 3.021 | 2.284 | 3.138 |
| Weekly averages | | | |
| KPSS | 0.859 | 0.644 | 1.0015 |
| Rank KPSS | 1.064 | 0.722 | 1.0799 |

The 5% critical value is 0.463

across days, we calculated the largest share for Monday (23%) while the other days are very close to an average value of 13%.

The fact that price convergence occurred slightly more frequently at day-time suggests to us that the coupling mechanism is particularly useful when the market needs it.

If we turn to the analysis of the two price series, looking at the distribution of the difference of their logarithms in Fig. 4, we see that the shapes of the estimated densities change even more markedly than their means. As suggested by the data contained in Table 1 and the related comments, since January 2011 there is a positive probability that the two prices are equal but, at the same time, in 2012 and 2013 the right tails are much thicker. By testing the equality of the medians over the 4 years using the Kruskal–Wallis test, we reject the null (equal medians) with a virtually zero $p$ value. Thus, we expect some form of nonstationarity in the log-price difference time series.

In order to test if the introduction of the coupling mechanism had an effect on the volatility of the electricity prices in the two country, we applied the Kruskal–Wallis test also to the absolute value of the median-centered prices in both markets: the test was not significant for Northern Italy, but strongly significant for Slovenia. The coupling mechanism significantly increased the volatility of Slovenian electricity prices (see also the first two panels of Table 1).

### 4.2 Dynamic analysis

The results of the preceding section let us expect different forms of nonstationarity in the prices and possibly in the cross-country difference of their logarithms. Here, we want to test for stationarity, unit roots and cointegration using the outlier-robust tests that we developed in Bosco et al. (2010) and Pelagatti and Sen (2013). In fact, by observing the price time series (Fig. 3), we notice a number of extreme values that make any normality-based procedure unreliable.

In particular, we exploit the results in Pelagatti and Sen (2013), where it is proved that by applying the well known KPSS test (Kwiatkowski et al. 1992) to the ranks of the observations we obtain a test statistic which is much more robust to the presence of extreme values but enjoys the same asymptotic distribution as the original KPSS

**Table 3** PLR test for the log of Slovenian and Italian prices

| Series | Stat | p value |
|---|---|---|
| Unit root test | | |
| BSP | 0.623 | 0.499 |
| GME | 0.326 | 0.591 |
| $H_0$: rank ≤ | PLR | p value |
| Cointegration test | | |
| 0 | 27.565 | 0.004 |
| 1 | 0.346 | 0.572 |

statistic. The Rank KPSS test (and also the KPSS) rejects the null of stationarity at any considered price frequency (hourly, daily, weekly).

Using the same test, we can assess if the ratio of the prices is stationary. The result of applying the KPSS tests to the logarithm of the price ratio is also reported in Table 2 as "Diff": the null is rejected and therefore, using the terminology of De Vany and Walls (1999) we can conclude that the market coupling mechanism has not realised the *strong integration* of the two markets.

Although the ratio of prices does not appear stationary, there could be some other form of equilibrium between the prices formed in the two markets. Thus, if we found cointegration between the two log-price time series, albeit with a cointegrating vector different from $[1, -1]$, which the KPSS test rejected, again stealing from the terminology of De Vany and Walls (1999), we could speak of *weak integration*.

Since the finite sample distribution of the Johansen test can be rather different from the asymptotic one when heavy tails are present, we use a robust version of it proposed by Lucas (1997) based on a $k$-dimensional vector error correction model (VECM) with Student's $t$ innovations with 5 degrees of freedom (df):

$$\boldsymbol{\Delta y}_t = \boldsymbol{\delta} + \boldsymbol{\Pi y}_{t-1} + \boldsymbol{\Gamma}_1 \boldsymbol{\Delta y}_{t-1} + \ldots + \boldsymbol{\Gamma}_p \boldsymbol{\Delta y}_{t-p} + \boldsymbol{\varepsilon}_t, \tag{1}$$

with $\boldsymbol{\varepsilon}_t$ multivariate (elliptical) Student's $t$ with 5 df and covariance matrix $\boldsymbol{\Sigma}$.

For estimating the non-normal VECM we implement an EM algorithm based on iteratively re-weighted least squares adapted from Lange et al. (1989), and for the computation of the finite sample $p$ values we used the bootstrap strategy of Swensen (2006): for $r = 0, 1, \ldots, k-1$,

1. estimate the unrestricted model under Student's $t$ innovations, and compute the relative residuals $\hat{\varepsilon}_{p+2}, \ldots, \hat{\varepsilon}_T$;
2. estimate the rank $= r$ model under Student's $t$ innovations;
3. using the VECM, generate bootstrap samples $\{\boldsymbol{y}_{p+1}^{(i)}, \ldots, \boldsymbol{y}_T^{(i)}\}$, using the first $p$ observations $\boldsymbol{y}_1, \ldots, \boldsymbol{y}_p$ as initial values, the parameters of the restricted model estimated at step 2., and shocks re-sampled from $\hat{\varepsilon}_{p+2}, \ldots, \hat{\varepsilon}_T$ of step 1;
4. compute the pseudo-likelihood ratio (PLR) statistic for testing hypotheses $H_0$ : rank$(\boldsymbol{\Pi}) \leq r$ vs. $H_1$ : rank$(\boldsymbol{\Pi}) = k$ for each bootstrap sample of step 3.

For each $r$, the bootstrap $p$ value for the PLR test is given by the relative frequency of bootstrapped PLR statistic replications, which are greater than the PLR statistic for the original sample. Of course, this test can be used also for testing for a unit root, if only one series is provided.

We apply this testing strategy only to the log of weekly mean prices for two reasons: (1) the periodicities due to within-day and within-week seasonal components are averaged out, (2) since we can think of our price time series as having a stochastic low-frequency trend buried into extremely volatile and leptokurtic noise, the resulting process has an important moving average (MA) component that VAR/VECM models are not able to deal with, and by taking means over 168 observations a relevant part of the noise is also averaged out making the MA component negligible.

From Table 3 we can conclude that there is a cointegration relation between the two log-price time series. The estimated cointegration and adjustment vectors are

$$\boldsymbol{\beta} = [1.00 \quad -0.93]^{\top}, \qquad \boldsymbol{\alpha} = [-0.33 \quad 0.02]^{\top},$$

where the order of the variables is log(BSP), log(GME)). In order to assess if there is a leader and a follower in the market price formation, we tested for the weak exogeneity of each of the two variables using, again, a bootstrap strategy applied to the VECM(2) model we applied to the weekly log-prices. In particular,

1. estimate the cointegrated VECM under Student's $t$ innovations, and compute the relative residuals $\hat{\varepsilon}_{p+2}, \dots, \hat{\varepsilon}_T$;
2. fix to zero the adjustment coefficient under test in the vector $\boldsymbol{\alpha}$;
3. using the VECM, generate bootstrap samples $\{\boldsymbol{y}_{p+1}^{(i)}, \dots, \boldsymbol{y}_T^{(i)}\}$, exploiting the first $p$ observations $\boldsymbol{y}_1, \dots, \boldsymbol{y}_p$ as initial values, the parameters of the estimated model modified as indicated at step 2., and shocks re-sampled from the $\hat{\varepsilon}_{p+2}, \dots, \hat{\varepsilon}_T$ obtained in step 1;
4. record the values of the adjustment coefficient under test estimated on each bootstrap sample of step 3 and compute the proportion of times their absolute values are larger than the absolute value of the estimate obtained on the original sample (step 1).

The adjustment coefficient for the Italian market is rather small (0.02) and, indeed, the bootstrap-based $p$ value for the hypothesis that its population value is equal to zero (i.e., weak exogeneity of GME prices) does not lead to the rejection of the null ($p$ value = 0.64). On the contrary, the weak exogeneity of Slovenian prices is strongly rejected ($p$ value < 0.0001). The conclusion is that only Slovenian prices adjust their dynamics in order to preserve the equilibrium relationships with Italian prices. This result is expected given that the two markets are considerably different in size and Italy, virtually a net importer, is characterized by inelastic demand.

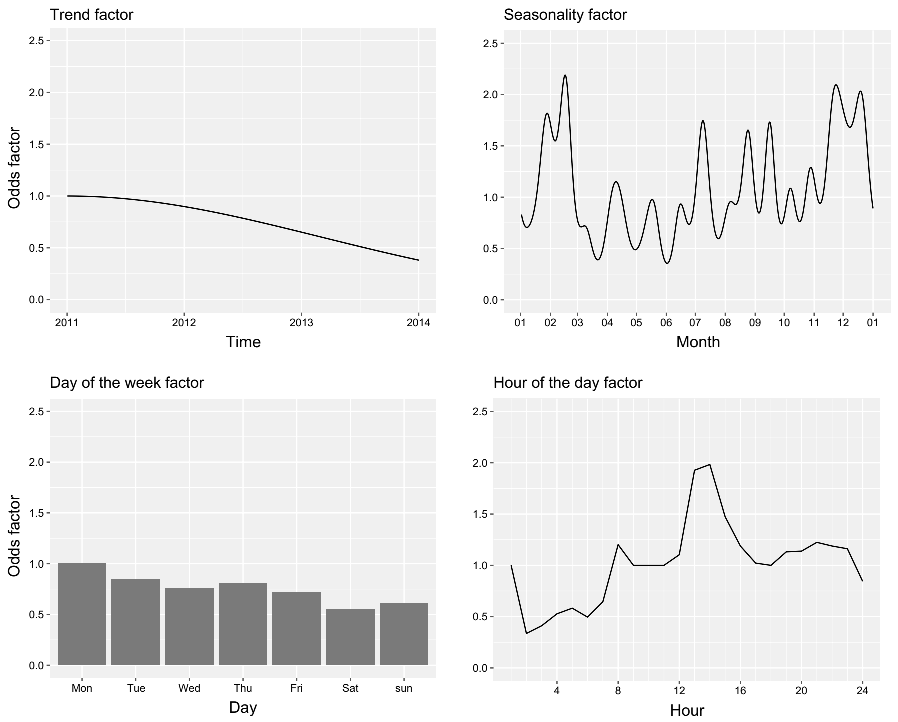


**Fig. 5** Component factor for each component influencing the probability of perfect coupling

## 4.3 Factors influencing the perfect price alignment

In order to assess what influences the probability of the two markets being perfectly coupled (i.e., the electricity prices in Italy and Slovenia are identical), we fitted two LASSO-regularized logistic regressions (Tibshirani 1996): one taking into account a polynomial trend and seasonal variables and one also including 24 lags of the response variable.[18] In formulas, let $y_t$ be the response variable taking the value 1 if the market are perfectly coupled (same price) and 0 otherwise (different price):

$$\operatorname{logit}\left[\Pr(y_t = 1)\right] = \alpha + \beta_1 t + \beta_2 t^2 + \sum_{i=1}^{7} \delta_i D_{it} + \sum_{j=1}^{20} \phi_j \cos(\omega_j t) + \varphi_j \sin(\omega_j t) \tag{2}$$

[18] The reader not acquainted with shrinkage and regularization methods can refer to the excellent book of Hastie et al. (2009, Section 3.4). The models in this section of the paper can be interpreted as logistic regressions for which the selection of the significant coefficients takes part during the estimation and not by means of post-estimation tests.

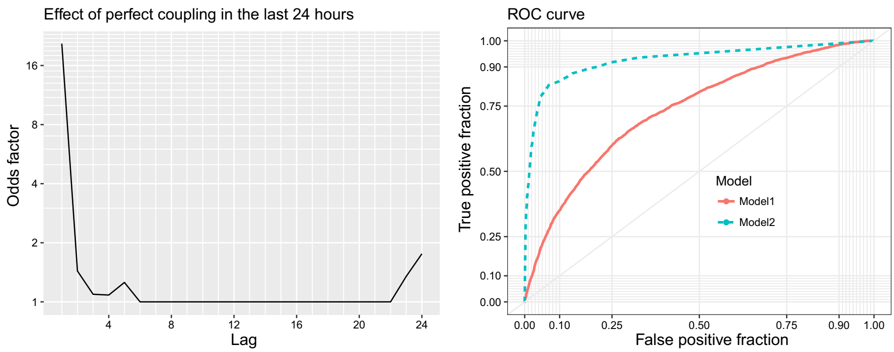


**Fig. 6** Left panel: exponential of the coefficients (odds factor) of each lag of the response variable. Right panel: ROC curves for the two models

$$\text{logit}\left[\Pr(y_t = 1)\right] = \alpha + \beta_1 t + \beta_2 t^2 + \sum_{i=1}^{7} \delta_i D_{it} + \sum_{j=1}^{20} \phi_j \cos(\omega_j t) + \varphi_j \sin(\omega_j t) + \sum_{k=1}^{24} \nu_k y_{t-k}, \tag{3}$$

where $D_{it}$ is a weekday dummy (i.e., it equals 1 when $t$ is in the weekday $i$ and 0 otherwise), $\omega_j = 2\pi j/8760$, so that the first sinusoid in the regression has period 1-year and the others are its first 19 harmonics (i.e., they take care of the yearly periodicity in a smooth way) and all the other Greek letters represents coefficients to estimate.

The " significant" variables in the two models are selected by maximizing the log-likelihood subject to a L1 penalization: if $\boldsymbol{\theta}$ is the vector of coefficients and $\ell(\cdot)$ the log-likelihood function, the LASSO-regularized objective function is given by

$$\ell(\boldsymbol{\theta}) - \lambda||\boldsymbol{\theta}||_1.$$

In order to fix the value of $\lambda$, which determines the importance of the penalization, we split the sample in six folds of a semester each and implemented a cross validation scheme.

The effect of the various components on the probability of perfect coupling is depicted in Fig. 5. Notice that on the $y$-axis we report the multiplicative effect of each component on the odds (which we call component factor):

$$\text{Odds}_t = \frac{\Pr(y_t = 1)}{\Pr(y_t = 0)} = \exp(\alpha)\exp(\boldsymbol{\theta}'\boldsymbol{x}_t) = 0.36 \times \text{ComponentFactor}_t,$$

with $\alpha$ intercept, $\boldsymbol{\theta}$ vector of all other coefficients and $\boldsymbol{x}_t$ vector of regressors at time $t$.

There is a clear negative effect of the time trend: the odds for a perfect coupling reduce by some 50% during the first 3 years of the coupling mechanism.[19] As for the seasonal effect, the probability of coupling increases in February, at the beginning of July and between November and December and decreases in the period March–June. The day of the week effect on the probability of perfect coupling is particularly negative on weekends, when the odds decrease by more than 40%. Finally, the probability of perfect coupling is low during the first hours of the morning, while it peaks between the 12th and 15th hour of the day.

If we add 24 lags of the response variable to the regressors and estimate model (3), then all the previously estimated coefficients are set to zero and the only "significant" coefficients are the ones corresponding to the lags 1–5 and 22–24 of the response variable. All these coefficients are positive, meaning that a perfect coupling event in those past hours increases the probability of perfect coupling in the present hour. The exponential of these coefficients is depicted in the left panel of Fig. 6. If in the hour preceding the current one in the two markets prevailed the same price, then the odds that in the current hour we observe perfect coupling increase by 22 times. A perfect coupling 24 h ago increases the odds of the current hour by almost two times. If in all the significant lags the markets were in perfect coupling, then the odds increase by 170 times. However, in this second model the baseline odds are much lower than in the previous one: $\exp(\alpha) = 0.045$. If no coupling took place in the last 24 h, then the probability of observing perfect coupling is only 4.3%.

We can compare the predictive ability of the two model we fitted by observing the right panel of Fig. 6. The second model does a much better job than the first: its ROC curve is uniformly higher (North-West) than the one of the first model. This result was expected, since the second model nests the first one, but the difference in the predictive ability of the two models is striking. All the information needed to predict the response variable is contained in the last 24 h of the response variable and all the other regressors do not seem to add any relevant detail.

## 5 Conclusions

We analyzed the clearing prices formed in the Italian and Slovenian electricity exchanges before and after the mechanism of market coupling was implemented and we observed that, although some form of price equilibrium has been reached as the cointegration relation between the two log-price time series proves, the two markets are still far away from being two strongly integrated markets.

North Italian prices are much higher than Slovenian prices and the capacity constraints for more then 80% of the times limit the transmission of the whole quantity of electricity demanded on the Italian side. Before the implementation of the market coupling the Italian demand was not fully matched some 90% of the times and so there is an improvement but it has a rather limited impact. The values of

[19] Looking at Table 1, we notice that the event of strong market integration decreased during the sample period. The two results are therefore mutually consistent.

the cointegration vector show that Slovenian prices tend to amplify the volatility of the common component, and this fact is probably due to the two regimes of Slovenian prices: aligned to the higher Italian prices (16.5% of the times in 2013), lower then Italian prices (82.4% of the times in 2013). From the weak exogeneity tests, we can conclude that Italian prices tend to lead Slovenian prices, which in turn tend to adjust and preserve the long-run equilibrium implied by the cointegration relation.

It is surprising how Slovenian producers were able to cope with the drastic increase in the demand on the BSP day-ahead market without significantly affecting the wholesale prices.

We also investigate the factors influencing the probability of perfect coupling of the two markets using a regularized logistic regression. We find that prices are perfectly aligned when demand is high, but not so high to saturate the interconnection capacity: in July and in Winter months coupling is more likely and, during the day, the highest probability of coupling occurs between the 12th and 15th, while it is low in the very first hours of the day and in weekends. However, when lags of the response variables are included in the model, we find that the only relevant information for predicting the coupling event are recent (last 1–4 and 23–24 h) realizations of perfect coupling.

From a statistical point of view, in this paper, as in Bosco et al. (2010) and Pelagatti and Sen (2013), we shown how classical normality-based statistical techniques can be adapted to successfully deal with the extreme features of electricity price time series.

## References


Bosco, B., Parisio, L., Pelagatti, M., & Baldi, F. (2010). Long run relations in European electricity prices. *Journal of Applied Econometrics*, *25*(5), 805–832.

Chao, H. P., & Peck, S. (1996). A market mechanism for electric power transmission. *Journal of Regulatory Economics*, *10*(1), 25–59.

Creti, A., Fumagalli, E., & Fumagalli, E. (2010). Integration of electricity markets in europe: Relevant issues for italy. *Energy Policy*, *38*(11), 6966–6976.

De Vany, A., & Walls, W. (1999). Cointegration analysis of spot electricity prices: Insights on transmission efficiency in the western US. *Energy Economics*, *21*(5), 435–448.

Ehrenmann, A., & Smeers, Y. (2005). Inefficiencies in european congestion management proposals. *Utilities Policy*, *13*(2), 135–152.

Gianfreda, A., Parisio, L., & Pelagatti, M. (2016a). The impact of RES in the Italian day-ahead and balancing markets. *The Energy Journal*, *37*, SI2.

Gianfreda, A., Parisio, L., & Pelagatti, M. (2016b). Revisiting long-run relations in power markets with high RES penetration. *Energy Policy*, *94*, 432–445.

Glachant, J. M. (2010). The achievement of the EU electricity internal market through market coupling. EUI Working Papers RSCAS/87

Hastie, T., Tibshirani, R., & Friedman, J. (2009). *The elements of statistical learning* (2nd ed.). Berlin: Springer.

Keppler, J. H., Phan, S., & Le Pen, Y. (2016). The impacts of variable renewable production and market coupling on the convergence of French and German electricity prices. *The Energy Journal*, *37*(3), 343–359.

Kiesel, R., & Kusterman, M. (2016). Structural models for coupled electricity markets. *Journal of Commodity Markets*, *3*(1), 16–38.

Koban, V. (2017). The impact of market coupling on hungarian and romanian electricity markets: Evidence from the regime-switching model. *Energy and Environment*, *28*(5–6), 621–638.

Kwiatkowski, D., Phillips, P. C. B., Schmidt, P., & Shin, Y. (1992). Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root? *Journal of Econometrics*, *54*(1–3), 159–178.

Lange, K. L., Little, J. A., & Taylor, J. M. G. (1989). Robust statistical modeling using the *t* distribution. *Journal of the American Statistical Association*, *84*, 881–896.

Lucas, A. (1997). Cointegration testing using pseudolikelihood ratio tests. *Econometric Theory*, *13*, 149–169.

Ochoa, C., & van Ackere, A. (2015). Winners and losers of market coupling. *Energy*, *80*, 522–534.

Parisio, L., & Bosco, B. (2008). Electricity prices and cross-border trade: Volume and strategy effects. *Energy Economics*, *30*(4), 1760–1775.

Pelagatti, M. M., & Sen, P. K. (2013). Rank tests for short memory stationarity. *Journal of Econometrics*, *172*(1), 90–105.

Swensen, A. R. (2006). Bootstrap algorithms for testing and determining the cointegration rank in VAR models. *Econometrica*, *74*, 1699–1714.

Tibshirani, R. (1996). Regression shrinkage and selection via the lasso. *Journal of the Royal Statistical Society Series B (Methodological)*, *58*(1), 267–288.

Zachmann, G. (2008). Electricity wholesale market prices in Europe: Convergence? *Energy Economics*, *30*(4), 1659–1671.

Zani, A., Benini, M., Gelmini, A., Migliavacca, G., & Siface, D. (2012). Assessment of the impact on the Italian electricity market of a price coupling with neighbouring countries. In *IFAC Proceedings of 8th power plant and power system control symposium* (Vol. 45, No. 21, pp. 687 – 692)