Nuno Carvalho Figueiredo[1,3] (corresponding author)
nuno.figueiredo@portugen.com
Patrícia Pereira da Silva[1,2,3]
patsilva@fe.uc.pt

[1]INESC Coimbra
Rua Antero de Quental, 199, 3030-030 Coimbra, Portugal
Phone: +351 239 851040/9
Fax: +351 239 824692
[2]Faculty of Economics of the University of Coimbra
Av Dias da Silva, 165, 3004-512 Coimbra, Portugal
Phone: + 351 239 790 500
[3]Energy for Sustainability Initiative - University of Coimbra, Portugal
Sustainable Energy Systems – MIT-P

Abstract

This paper aims to assess some determinants on the integration level of the South West Europe regional electricity spot markets created under the initiative launched by the European Regulators Group for Electricity and Gas. The integration of the European South-West regional electricity spot market relies on the physical interconnection between two pairs of Transmission Systems: Portugal-Spain and Spain-France. Interconnection capacity is thought to be critical to ensure electricity market integration and was therefore studied. Two other determinants were included in our study, corresponding to weather conditions: temperature and wind. Whilst temperature is thought to have influence on demand, wind on the other hand should have influence on available generation. Results obtained from a vector autoregression model specification show interconnection capacities related exogenous variables to not improve the model, whilst average temperature contributes slightly to improve the model. It is to note that the introduction of the exogenous variable average wind speed improves all models' specification. Strong integration was found between MIBEL markets, leading to the conclusion that Price Splitting mechanism is efficient and contributes to the integration of spot electricity markets. Also, as demonstrated by Grange-causality and impulse response analysis, there is a weak integration level between MIBEL and Powernext.

Keywords: Electricity market integration; South-West REM; VARX modeling

EXPLANATORY VARIABLES ON SOUTH-WEST SPOT ELECTRICITY MARKETS INTEGRATION

Introduction

The Council Directive 90/547/EEC of 29 October 1990 on the transit of electricity through transmission grids (European Union, 1990a) and Council Directive 90/377/EEC of 29 June 1990 concerning a procedure to improve the transparency of gas and electricity prices charged to industrial end-users (European Union, 1990b), provided the first steps for the creation of the internal European electricity market (Bower, 2002).

The European Directive 2003/54/EC and lately the European Directive 2009/72/EC reviewed the European Directive 96/92/EC which for the first time established common rules for the various electricity markets in Europe, based on the liberalisation of the sector without prejudice of the public service required and the access by the generators and consumers to the transmission and distribution grids (Jamasb and Pollitt, 2005). These requirements are guaranteed by regulating authorities established in each country (Silva and Soares, 2008).

The European Directive 2001/77/EC repealed by the European Directive 2009/28/EC called for the promotion of electricity generation by renewable energy sources (RES) in Europe in order to reduce dependency on imported fossil fuels and to allow the reduction in greenhouse gas (GHG) emissions. The RES electricity (RES-E) generation capacity in Europe was 239.2 GW by 2010 with 52.1% hydroelectric, 25.7% wind, 17.86% biomass, 3.3% solar, 0.93% geothermal and 0.08% tidal or wave generation (Jäger-waldau et al., 2011). The RES-E generation technologies are in different stages of development which explain the different shares of deployment achieved in each technology (Brown et al., 2011). The large deployment of RES-E generation in Europe was achieved by strong financial support mechanisms (Meyer, 2003), like feed-in tariffs, fiscal incentives, tax exemptions and other (Jager et al., 2011).

To guarantee the supply of electricity, reduce costs, maintain competition and ensure security of supply, whilst respecting the environment, are the objectives set for European energy policies. However different degrees of market opening and development of interconnectors between electricity transmission grids across European countries are observed. European countries took necessary measures to facilitate transit of electricity between transmission grids in accordance with the conditions laid down in the Directives. The adequate integration of national electricity transmission grids and associated increase of electricity cross-border transfers should ensure the optimization of the production infrastructure.

In 2006 the European Regulators Group for Electricity and Gas (ERGEG - currently the Agency for the Cooperation of Energy Regulators – ACER established by European Commission Regulation 713/2009 of 13 July 2009) launched seven Electricity Regional Initiatives (Karova, 2011; Meeus and Belmans, 2008) for the creation of seven Regional Electricity Markets (REMs): Baltic States (Estonia, Latvia, Lithuania); Central East (Austria, Czech Republic, Germany, Hungary, Poland, Slovakia, Slovenia); Central South (Austria, France, Germany, Greece, Italy, Slovenia); Central West (Belgium, France, Germany, Luxembourg, Netherlands); Northern Europe (Denmark, Finland, Germany, Norway, Poland, Sweden); South West (France, Portugal, Spain); and France-UK-Ireland (France, Republic of Ireland, UK). The objective for the creation of these REMs was to provide an intermediate step for the consolidated European Electricity Market (CEER, 2015; ERGEG, 2006).

Consequently, the aspect of transmission costs determination plays an important role and its allocation methods are usually either Flat Rate based or Flow-based. Flat rate methods are simple to calculate and implement, however, according to (Galiana et al., 2003) unfair to generators that use less capacity and extent of the transmission lines.

On the other hand, flow-based costs are most commonly used due to their dependence on the capacity and extent used by each generator of the transmission lines. Explicit auctioning, where interconnector capacity is sold to the highest bidder or implicit auctioning, which integrates electricity and transmission markets and also called Market Splitting/Price Coupling, are both used across Europe (Coppens and Vivet, 2006).

In the Spain-France interconnection, the method of explicit auctioning is used however the mechanism of Market Splitting is applied to the Portuguese-Spanish interconnection.

In this framework, an initiative, denominated Price Coupling of Regions (PCR) was launched at the Florence Regulatory Forum in 2009 by three power exchanges: Nordpool, EPEX and MIBEL (Europex, 2009), to be implemented by the end of 2012. In the mean time additional members joined the initiative, APX-Endex, Belpex and GME, reaching the 2860 TWh/year of potential electricity trading (Europex, 2011) and to be fully implemented by the end of 2014.

Building on previous work by the authors (Figueiredo and Silva, 2012), the objective of this paper is to assess the level of integration of the South West REMs. In Section 2 spot electricity market data used in this study is presented and discussed and in section 3 VAR model specifications are presented. Analysis and results of additional impulse response functions to account for causal impacts are presented and discussed in Section 4 and, finally, in Section 5 final remarks can be found.

The French electricity market

In France, there was no privatisation and no unbundling (Newbery, 2005). With several acts of legislation, France managed to carry out the electricity sector reform (through the law 2000-108 of the 10th of February) without restructuring the main operator. An electricity market was created around a public monopoly (Glachant and Finon, 2004). The law 2000-108 of the 10th of February also created the "Commission de Régulation de L'énergie" (CRE) the French regulator (Journal Officiel de la République Française, 2000).

It was considered that competition would come from abroad through the interconnections with the various European countries. The main reasoning behind this was the vast nuclear power capacity and associated low variable cost electricity (Newbery, 2005). EDF has currently 97.2 GW of installed electric capacity, of which 63.7 GW are of nuclear power and owns the complete transmission grid (EDF Group, 2010).

The French electricity day-ahead market, Powernext, started operation in November 2001 (Bower, 2002) and by January 2006 explicit capacity auctions on interconnections was introduced (Commission de Régulation de L'énergie, 2011). The market coupling between France, Belgium and the Netherlands was launched in November 2006 and in November 2010 this was extended to Luxembourg and Germany (after the merger of Powernext and EEX, the new EPEX Spot and EPD futures in April 2009). "Powernext Intraday" and "Powernext Continuous" markets were introduced in July 2007.

On the 7th of December 2010 the law 2010-1488 was issued, the "Loi NOME", establishing a new model for the electricity market. The main objective of this law was to effectively open the market by resolving the problem of the competitors' access to competitive sources of electricity. It ensures the transitory right of access to the Historical Nuclear Regulated Electricity (ARENH) by alternative suppliers at a regulated price and volume, which are both determined annually by CRE with a maximum volume limitation by law to 100 TWh/year (Journal Officiel de la République Française, 2010).

Additional details on the French electricity market can be found in Lévêque (2010).

The Spanish electricity market

An agreement was reached between the authorities and the electricity companies late in December 1996 (Ministerio de Industria y Energía - Spain, 1996), allowing for the electricity sector reform.

The law for the electricity sector issued in November 1997 established the electricity sector regulation with the objectives to guarantee the supply, the quality of supply at the minimum possible cost while respecting the environment. The existing public service was replaced by the guarantee of supply for all consumers; the electrical sector was privatised on the generation and commercialisation sides and regulated on the transmission and distribution sides (Boletín Oficial del Estado - Spain, 1997). The transmission system was assigned to Red Eléctrica de España (REE) and in January 1998 an electricity spot market was introduced in Spain (OMEL).

After successive delays the Iberian electricity market (MIBEL) started operation in July 2007 and by 2008 the corresponding spot electricity market comprised 88% of total demand (Zachmann, 2008).

Additional details on the Spanish electricity market can be found in Crampes (2004), Furió & Lucia (2009) and Garrué-Irurzun & López-García (2009).

The Portuguese electricity market

The Decree-law 7/91 of the 8th of January established the conversion of the Portuguese public electricity company Electricidade de Portugal (EDP) into a private company still owned by the state. This would allow the unbundling of the Portuguese electricity sector and later privatisation.

The re-privatisation of EDP was started in 1997 after the issue of the Decree-law 56/97 of the 14th of March which determined on the first phase the sale of 29.99% of its capital and was followed by several other phases, the last one in 2012.

The transmission system operation was assigned to Redes Energéticas Nacionais (REN), created in 1994, under the ownership of EDP. In the end of the year 2000 the Portuguese state acquired 70% of REN from EDP. Only in 2007 the initial phase of REN's privatization (Redes Energéticas Nacionais, 2012a) took place. Currently EDP still owns a 5% share in REN (Redes Energéticas Nacionais, 2012b).

The Portuguese regulator for the energy sector (ERSE) was created in 1995 with the Decree law 187/95 of 27th of July (Diário da República Portuguesa, 1995) and has since then been adjusted through several other laws to the requirements of the energy sector and EU requirements (Silva, 2007).

The Iberian electricity market was only a reality in July 2007 after several years of preparation and negotiation between the Portuguese and the Spanish states. The MIBEL is composed by a spot (OMIE) and a bilateral (OMIP) electricity markets (Conselho de Reguladores do MIBEL, 2009).

Additional details on the Portuguese electricity market can be found in Amorim et al. (2010).

Interconnections offer numerous advantages under normal operating conditions, such as optimal power station daily production, increasing opportunities for operation with renewable energies, the creation of competition and improvement of supply security.

However interconnectors are limited and have constraints due to physical behavior. Electrical current behaves like a fluid in a pipe; it flows through the easiest path. Therefore we have high voltage grids interconnected through many interconnectors placed in different geographic positions, which originate unidentified flows not necessarily related with cross-border contracts. Also, a consumer that contracted with one generator across the border will probably receive electricity from a different generator. All this physical properties of high voltage grids can create congestion of transmission lines and interconnectors causing the so called Loop Flow Problem (Coppens and Vivet, 2006).

Constraints have then to be managed by the Transmission System Operators (TSO) and specifically cross-border exchanges in electricity have to comply with European Community Regulation 1228/2003/EC of 26 June 2003 and later with European Community Regulation 714/2009 of 13 July 2009. These Regulations established initially a set of rules for cross-border exchanges in electricity, in order to enhance competition, establish a compensation mechanism for cross-border flows of electricity, setting principles on cross-border transmission charges and allocating available capacities of interconnections (European Union, 2003). With the latest Regulation the creation of the European Network of Transmission System Operators (ENTSO) was established, aiming to prepare network codes to guarantee an efficient transmission network management, together with allowing trade and supply of electricity across borders.

Transmission Costs allocation methods can be Flat Rate based or Flow-based. Flat rate methods are simple to calculate and implement, however unfair to generators that use less capacity and extent of the transmission lines (Galiana et al., 2003).

Flow-based costs are most commonly used due to their dependence on the capacity and extent used by each generator of the transmission lines. Explicit auctioning, where interconnector capacity is sold to the highest bidder or implicit auctioning, which integrates electricity and transmission markets and also called Market Splitting/Price Coupling, are both used across Europe (Coppens and Vivet, 2006).

During the period of this study, the method of explicit auctioning is used in the Spain-France interconnection, however the Market Splitting mechanism is applied to the Portuguese-Spanish interconnection.

The Spain-France electrical interconnection currently consists of four HV lines: Arkale-Argia, Hernani-Argia, Biescas-Pragneres, Vic-Baixas. These have a total commercial exchange capacity of 1,400 MW for transits from France to Spain and 1,100 MW for transits from Spain to France.

To fulfill the requirements of the European Commission a new HV line is being built by INELFE, a consortium with equal shares of the Spanish National Grid (Red Eléctrica de España - REE) and French National Grid (Réseaux de Transport d'Électricité - RTE). This new line will double the current interconnection capacity and will be in operation by 2015 (INELFE, 2011). The development of the interconnection capacity will allow a better market integration and provide additional security of electricity supply, being considered a critical factor to ensure integration (Everis and Mercados EMI, 2010).

The Portugal-Spain electrical interconnection currently consists of eleven HV lines, of which the last two have in practice no use, with an average capacity of 1800 MW: Alto Lindoso – Cartelle 1, Alto Lindoso –

Cartelle 2, Lindoso – Conchas, Lagoaça – Aldeadávila, Pocinho – Aldeadávila 1, Pocinho – Aldeadávila 2, Pocinho – Saucelle, Falagueira – Cedillo, Alqueva – Brovales, Tavira – P. Guzman.

A new interconnection line between Viana do Castelo and Fontefria is planned to be constructed and forecasted to be in service by 2017, which with several other internal line reinforcements will allow the completion of the interconnection capacity between Portugal and Spain of 3000 MW, essential for the joint Iberian electricity market MIBEL (Redes Energéticas Nacionais, 2015).

Data

Day-ahead spot electricity prices in €/MWh (base, peek and off-peak), obtained from *Datastream*, were used in this study from the 1st of January 2012 to the 31st of December 2014. The data for the day-ahead base, peak and off-peak spot electricity prices is plotted in Figure 1.

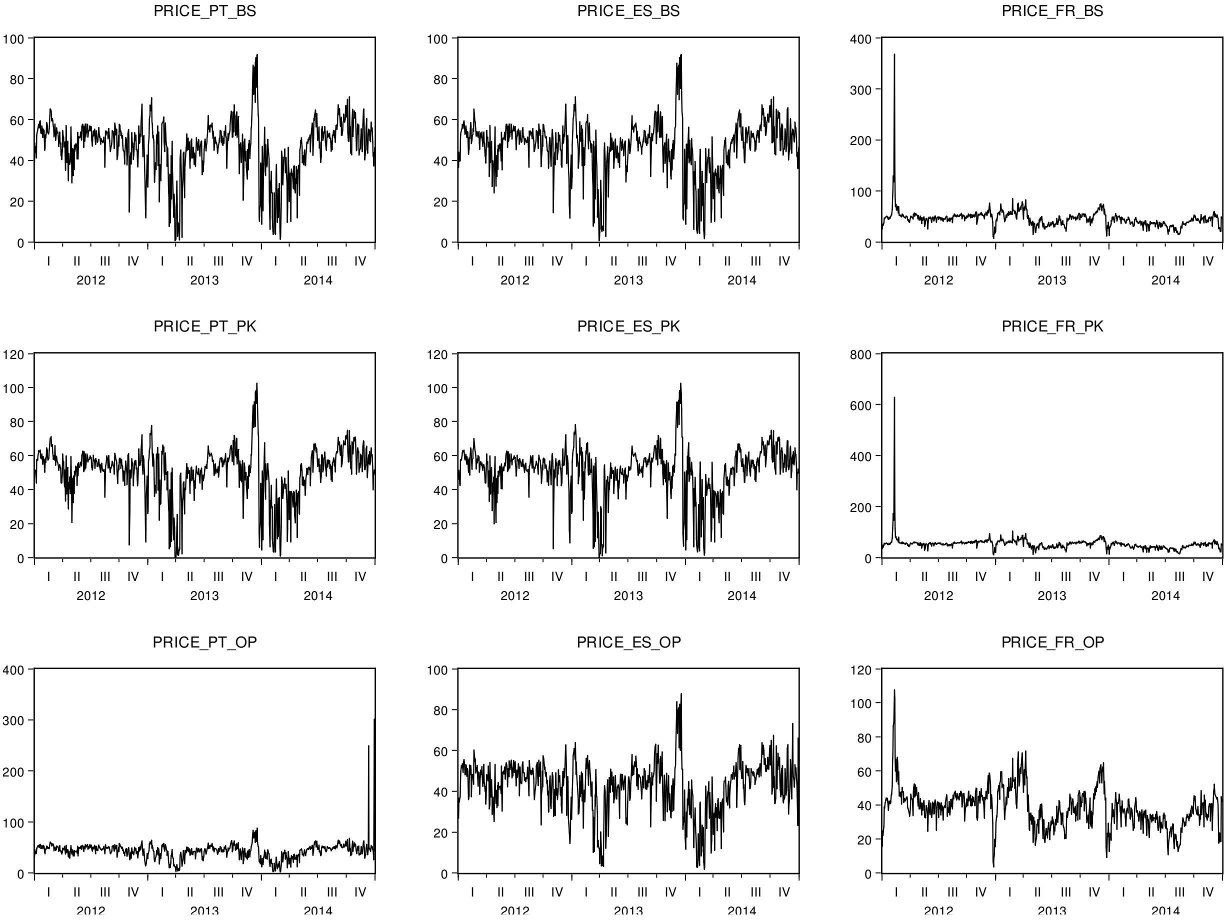

Figure 1 – Day-ahead base spot electricity prices – Price_PT (Portugal), Price_ES (Spain) and Price_FR (France)

Price spikes are observed in electricity markets, which confirms the high volatility behaviour of electricity spot prices, as in Goto and Karolyi (2004), Hadsell et al. (2004) and Higgs (2008). The limited possibility of storage, the physical characteristics of simultaneous electricity production and consumption, technical constraints in transmission and generating plants are the main reasons for these spikes (Coppens and Vivet, 2006; Silva and Soares, 2008).

After transforming the prices into their natural logarithms, to obtain directly the elasticity values from the parameter estimates, summary statistics were calculated (Table 1). Skewness and kurtosis values also indicate non-normal distribution, which is confirmed by JB statistic.

Unit root tests were made to all daily-log spot electricity prices. As per Table 2 we observe that all time series are considered to be stationary at 5% agreeing with findings in Park et al. (2006) and Bunn and Gianfreda (2010).

Daily average interconnection capacities were obtained from the corresponding system operator (REN, REE and RTE) and are plotted in Figure 2.

Daily weather data was retrieved from the website www.wunderground.com: maximum and minimum ambient temperatures (in degrees Celsius) and average wind speed (in km/h) for each country of the SWE REMs (Figure 3). Given the large number of installed wind power plants in the SWE electricity markets, it is believed to be a good approximation to use averaged weather variables across the existing weather stations linked to the www.wunderground.com website. In this way a country average is calculated for every hour and then averaged for every day. Maximum and minimum ambient temperatures were then used to calculate Heating Degree-days (HDD) and Cooling Degree-days (CDD) according to the UK Meteorological Office method (Mourshed, 2012; UK Climate Projections 2009, 2013).

It is to note the big variability in the average wind speed. Literature reports some related issues, as such: transport of excess production, electrical system fault endurance, available and flexible standby generating capacity and effective control or curtailment of wind power production (Benatia et al., 2013; Franco and Salza, 2011; Söder et al., 2007).

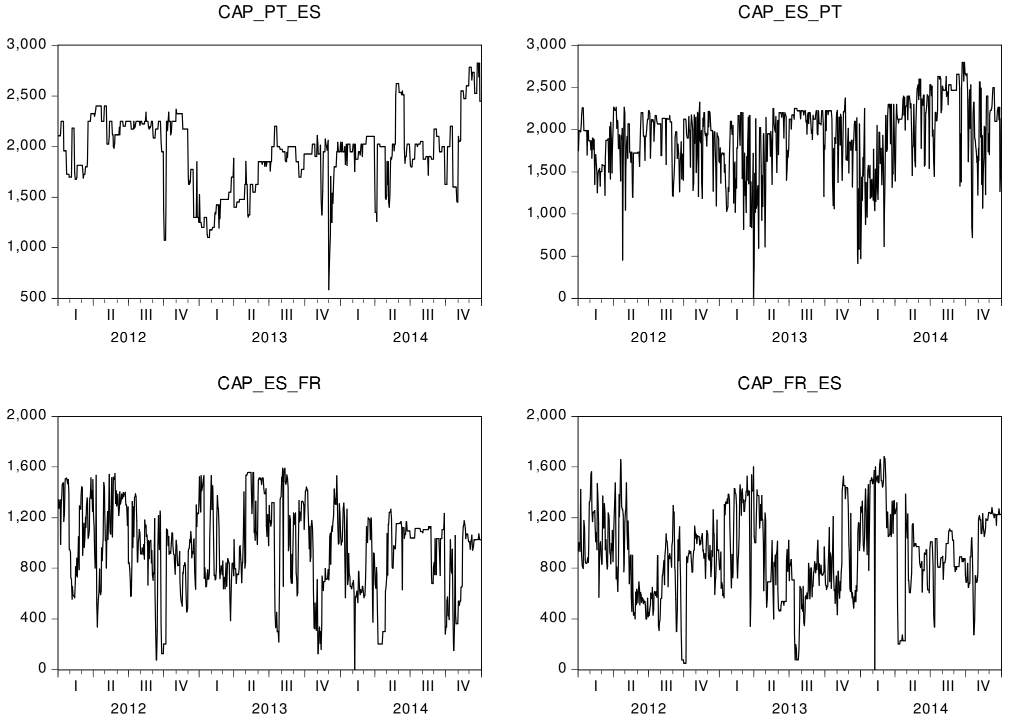

Figure 2 – Import and export interconnection capacities between Portugal-Spain and Spain-France [MW]

Table 1 - Summary Statistics Daily-log Spot Electricity Prices

	PRICE_PT_BS	PRICE_ES_BS	PRICE_FR_BS	PRICE_PT_PK	PRICE_ES_PK	PRICE_FR_PK
Mean	46.56047	46.75766	45.57176	50.50936	50.88954	52.8457
Median	49.2	49.15	45.71	53.4	53.42	53.31
Maximum	91.89	91.89	367.6	102.42	102.42	627.59
Minimum	0.79	0.79	7.11	0.05	0.05	10.67
Std. Dev.	13.64581	13.32416	17.45264	15.17455	14.85422	25.77347
Skewness	-0.91986	-0.884998	8.5148	-1.038287	-1.049672	14.57907
Kurtosis	5.079319	5.340286	151.869	5.358144	5.676603	318.9676
Jarque-Bera	251.4779	280.8955	732495.9	322.1068	377.5185	3284872
Probability	0	0	0	0	0	0
Observations	783	783	783	783	783	783

	PRICE_PT_OP	PRICE_ES_OP	PRICE_FR_OP	PT_HDD	ES_HDD	FR_HDD
Mean	43.08826	42.55379	38.2928	2.251454	3.330681	4.43684
Median	45.195	45.015	38.16917	1.282996	1.819442	3.077545
Maximum	301.285	87.805	107.6158	12.00704	14.10248	22.43006
Minimum	1.745833	1.72	3.538333	0	0	0
Std. Dev.	17.47134	12.71196	11.61162	2.363278	3.599877	4.265026
Skewness	5.878117	-0.644137	0.70576	1.149727	0.905703	0.953528
Kurtosis	87.1428	4.479365	6.233589	3.893398	2.752871	3.153219
Jarque-Bera	235494.4	125.5465	406.1317	198.5441	109.0414	119.4185
Probability	0	0	0	0	0	0
Observations	783	783	783	783	783	783

	PT_CDD	ES_CDD	FR_CDD	PT_WSAVG	ES_WSAVG	FR_WSAVG
Mean	0.874864	1.071543	0.900092	3.529939	5.966993	2.601971
Median	0	0	0	2.908853	4.976699	2.429253
Maximum	9.009729	8.91479	10.60773	12.22416	19.2016	10.84552
Minimum	0	0	0	0.275082	0.606043	0.042626
Std. Dev.	1.472858	1.751397	1.724336	2.205962	3.488747	1.39227
Skewness	2.252565	1.754339	2.685284	0.945743	1.29511	1.141516
Kurtosis	8.432273	5.339177	10.9702	3.41704	4.545661	5.79865
Jarque-Bera	1624.914	580.1562	3013.477	122.3973	296.8325	425.5825
Probability	0	0	0	0	0	0
Observations	783	783	783	783	783	783

	CAP_PT_ES	CAP_ES_PT	CAP_ES_FR	CAP_FR_ES
Mean	1943.556	1914.928	968.0859	907.9869
Median	2000	1991.667	1025	893.7917
Maximum	2825	2800	1592	1686
Minimum	583.3333	0	0	0
Std. Dev.	354.9334	422.2091	343.1235	338.215
Skewness	-0.354533	-0.830241	-0.412352	-0.138102
Kurtosis	3.246843	3.979948	2.663116	2.711556
Jarque-Bera	18.39094	121.2834	25.89208	5.203325
Probability	0.000101	0	0.000002	0.07415
Observations	783	783	783	783

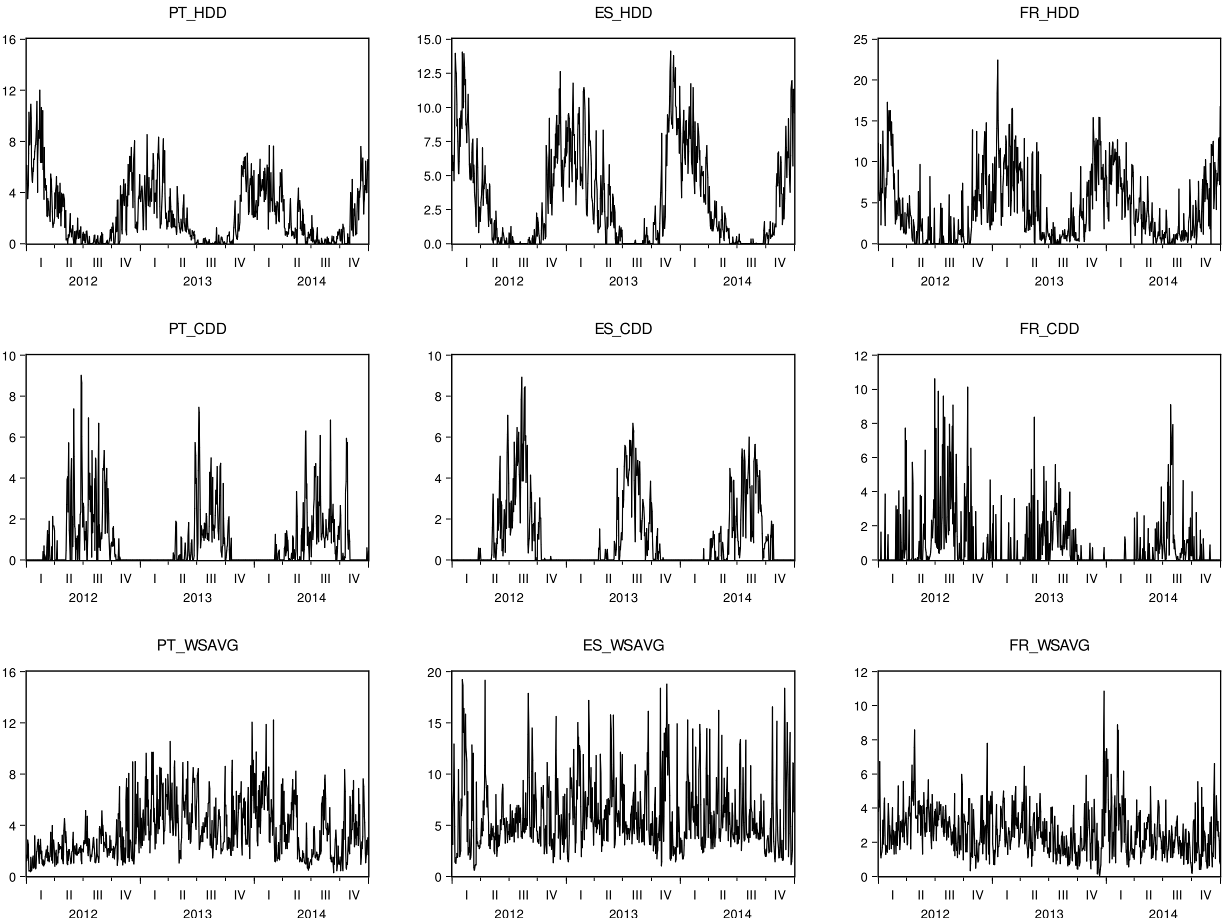

Figure 3 - HDD, CDD [ºC] and Average Wind Speed [km/h] in Portugal, Spain and France

Table 2 – Unit root tests

	L_PRICE_PT			L_PRICE_ES			L_PRICE_FR		
	Base	Peak	Off-peak	Base	Peak	Off-peak	Base	Peak	Off-peak
ADF test	-5.510	-5.081	-5.592	-5.743	-5.230	-5.855	-8.130	-6.507	-8.020
(p-value)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
PP test	-12.141	-11.938	-10.518	-12.837	-13.498	-10.083	-8.370	-10.173	-8.135
(p-value)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)

Model Estimation

The VAR model has proven to be especially useful for describing the dynamic behavior of economic and financial time series and for forecasting. It is known to provide superior forecasts to those from univariate time series models and elaborate theory-based simultaneous equations models. In addition to data description and forecasting, the VAR model is also used for structural inference and policy analysis (Lütkepohl, 2005; Sims, 1980). In structural analysis, certain assumptions about the causal structure of the data under investigation are imposed, and the resulting causal impacts of unexpected shocks or innovations to specified variables on the variables in the model are summarized. These causal impacts are usually summarized with impulse response functions, as is performed in this work.

A VARX model was then considered to proceed with the evaluation of the determinants in the electricity market integration, due to its ability in capture the linear interdependencies among multiple time series.

Considering a VARX model for the three log prices:

$$\mathbf{Y}_{\mathrm{t}}^{(\mathrm{z})} = \mathbf{C}^{(\mathrm{z})} + \sum_{\mathrm{i}=1}^{\mathrm{p}} \mathbf{A}_{\mathrm{i}}^{(\mathrm{z})}\mathbf{Y}_{\mathrm{t-i}}^{(\mathrm{z})} + \mathbf{B}^{(\mathrm{z})}\mathrm{X}_{\mathrm{t}}^{(\mathrm{z})} + \mathbf{u}_{\mathrm{t}}^{(\mathrm{z})} \qquad (1)$$

where z is the base, peak or off-peak model, $\boldsymbol{Y}_t^{(z)} = (l\_Price\_PT_t^{(z)},\ \ l\_Price\_ES_t^{(z)},\ \ l\_Price\_FR_t^{(z)})'$ the day-ahead electricity price matrix, $\boldsymbol{X}_t^{(z)}$ the exogenous variables matrix, $\boldsymbol{C}^{(z)}$ are (3x1) constant matrices, $\boldsymbol{A}^{(z)}{}_i$ and $\boldsymbol{B}^{(z)}$ are (1x3) coefficient matrices and $\boldsymbol{u}^{(z)}{}_t$ are (3x1) matrices of unobservable error terms. In order to determine the order of each the models, successive VAR models were estimated by a sequential test procedure, starting with the estimation of the models with $p = 15$ lags and calculating-down for lower lags the Schwarz Bayesian criterion (BIC) and the Hannan-Quinn criterion (HQC).

In Table 3 the best values for the endogenous variable lags where criteria are minimised are presented. For each model a lag exclusion Wald test was performed in order to detect lags where the respective coefficients do not present significance in the model, which were then removed as indicated. Autocorrelation testing in all models was performed (Davidson and Mackinnon, 2004).

Table 3 – Lag selection for estimated models

	Price VAR model				Price VARX model			
	Base							
Lag Length Criteria	Lags	SC	HQ	Lag removed	Lags	SC	HQ	Lag removed
	5	-1.908569	-2.087095*	NA	8	-1.906685	-2.330686*	5
	Off-peak							
Lag Length Criteria	Lags	SC	HQ	Lag removed	Lags	SC	HQ	Lag removed
	4	-1.8528	-1.997853*	3 and 5	4	-2.02962	-2.319726*	2 and 3
	Peak							
Lag Length Criteria	Lags	SC	HQ	Lag removed	Lags	SC	HQ	Lag removed
	9	-0.18936	-0.501781*	NA	9	-0.156834	-0.614308*	NA

Analysis and discussion of results

Weather conditions have impacts on both demand and supply of electricity. The estimated VARX model provides insights of the related dynamics between the considered exogenous variables and spot electricity prices.

CDD and HDD are considered proxies for electricity demand, therefore a positive contribution in the models is expected. The results shown in Table 4 demonstrate that the exogenous variables related with CDD do not contribute too much for the model specification, whereas HDD improves the model in some cases. Positive significant contributions are found for the Spanish HDD in both spot electricity prices for Portugal and Spain. However, it is interesting to note that the Portuguese HDD has significant negative contributions to these same prices, which might be related with weather dynamics (which were not modeled here) rather than price dynamics. The French HDD only provides a positive contribution to the spot electricity price in France. Furthermore, during peak periods only the Spanish HDD significant positive contributions on both Iberian spot electricity prices remain.

A relevant improvement in model specification is found by incorporating as exogenous variables the average wind speeds. It is expected that average wind speed contributes negatively to spot electricity prices due to the normally low marginal prices bid into spot markets. This is actually seen for almost all Portuguese, Spanish and French average wind speeds where significant negative contributions to spot electricity prices are found. Some small positive contributions are found, however weaher dynamics might explain these. It is to note that an increase of 1 km/h in the Portuguese average wind speed contributes to a 4,46% decrease in the base Portuguese spot electricity price (Table 4). Furthermore, there is a 3.06% negative contribution of the French average wind speed to the base Portuguese spot electricity price. However given the small existing interconnection between France and Spain, this contribution might be related with weather dynamics rather than arbitrage between markets.

It would also be expected that the growth in ATC would contribute to a higher level of arbitrage, thus with negative effects to spot electricity prices. However, ATC significant contributions to spot electricity prices do not have a major contribution to the model specification.

As per Figure 4 all three models satisfy the stability condition of no roots outside the unit circle.

Table 4 – Wind [km/h], HDD [ºC] and CDD [ºC] significant coeficients in the VARX model

Price	Base			Off-peak			Peak		
	Wind_PT	Wind_ES	Wind_FR	Wind_PT	Wind_ES	Wind_FR	Wind_PT	Wind_ES	Wind_FR
L_PRICE_PT	-4.46%	-0.70%	-3.06%	-3.98%	-0.89%	-2.89%	-4.40%		-2.85%
L_PRICE_ES	-3.92%	-0.82%	0.19%	-3.45%	-1.12%	-3.06%	-4.04%		-3.58%
L_PRICE_FR	-1.18%	0.49%	-2.60%	-1.34%	0.54%	-3.18%	-1.12%	0.55%	-2.36%
Price	Base			Off-peak			Peak		
	HDD PT	HDD ES	HDD FR	HDD PT	HDD ES	HDD FR	HDD PT	HDD ES	HDD FR
L_PRICE_PT	-2.28%	2.12%		-1.89%	1.58%			2.93%	
L_PRICE_ES	-2.40%	2.20%		-2.12%	1.54%			3.20%	
L_PRICE_FR			0.59%			0.65%			
Price	Base			Off-peak			Peak		
	CDD PT	CDD ES	CDD FR	CDD PT	CDD ES	CDD FR	CDD PT	CDD ES	CDD FR
L_PRICE_PT									
L_PRICE_ES									
L_PRICE_FR		0.98%			1.26%				

Granger Causality tests to the time-series variables and impulse response analysis displaying the responses of each daily-log price time-series to a standard error shock in one of the time-series were carried out to the models considered and are presented, respectively, in Table 6 and in Figure 5 to Figure 7.

Table 5 –ATC [MW] significant coeficients in the VARX model

Price	Base				Off-peak			
	ATC PT-ES	ATC ES-PT	ATC ES-FR	ATC FR-ES	ATC PT-ES	ATC ES-PT	ATC ES-FR	ATC FR-ES
PRICE_PT		0.02%	0.01%			0.02%	0.01%	
PRICE_ES	-0.01%	0.02%	0.01%	-0.01%	-0.01%	0.02%	0.01%	
PRICE_FR		0.00%	0.00%			0.00%	0.00%	

Price	Peak			
	ATC PT-ES	ATC ES-PT	ATC ES-FR	ATC FR-ES
PRICE_PT		0.02%		
PRICE_ES		0.02%	0.01%	
PRICE_FR			-0.01%	

Outcomes in Table 6 show that both MIBEL market prices fail to Granger-cause the Powernext market prices on a pairwise relation. This can likewise be observed in the impulse responses of the French spot electricity market prices, which are practically inexistent to shocks in any one of the MIBEL spot electricity market prices. In spite Powernext market prices Granger-cause the MIBEL_ES price in all models, the impulse response analysis indicates a very weak effect. Additionally, there is a Granger-causality relation between Powernext and MIBEL_PT base and peak prices, yet fairly weak as confirmed by the impulse response analysis.

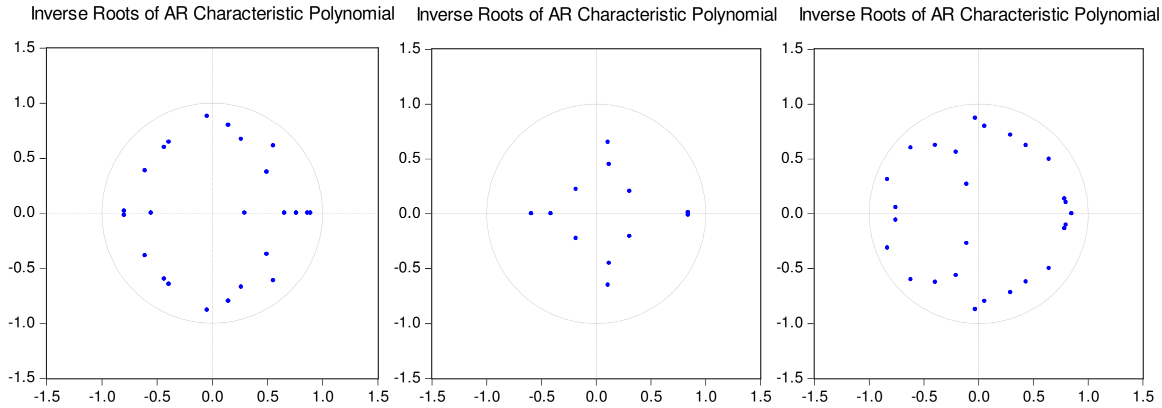

Figure 4 – Unit circle plot for base, off-peak and peak models (left to right)

Within Iberia both MIBEL prices Granger-cause each other in all base, peak and off-peak models, which confirms the good integration between both Iberian electricity markets. This is also seen in the impulse response plots with strong responses of the Spanish spot electricity price to shocks in the Portuguese spot electricity price in all base, off-peak and peak models and vice-versa.

Table 6 – Granger Causality test output

Base				Off-peak				Peak			
Dependent variable: L_PRICE_PT_BS				Dependent variable: L_PRICE_PT_OP				Dependent variable: L_PRICE_PT_PK			
Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.
L_PRICE_ES_BS	64.21	7	0.00	L_PRICE_ES_OP	7.48	2	0.02	L_PRICE_ES_PK	82.37	9	0.00
L_PRICE_FR_BS	9.85	7	0.20	L_PRICE_FR_OP	6.28	2	**0.04**	L_PRICE_FR_PK	16.57	9	0.06
All	75.22	14	0.00	All	13.69	4	0.01	All	96.15	18	0.00
Dependent variable: L_PRICE_ES_BS				Dependent variable: L_PRICE_ES_OP				Dependent variable: L_PRICE_ES_PK			
Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.
L_PRICE_PT_BS	59.98	7	0.00	L_PRICE_PT_OP	21.92	2	0.00	L_PRICE_PT_PK	81.87	9	0.00
L_PRICE_FR_BS	12.44	7	0.09	L_PRICE_FR_OP	3.49	2	0.17	L_PRICE_FR_PK	14.41	9	0.11
All	74.34	14	0.00	All	26.27	4	0.00	All	93.57	18	0.00
Dependent variable: L_PRICE_FR_BS				Dependent variable: L_PRICE_FR_OP				Dependent variable: L_PRICE_FR_PK			
Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.
L_PRICE_PT_BS	3.49	7	**0.84**	L_PRICE_PT_OP	2.65	2	**0.27**	L_PRICE_PT_PK	7.57	9	**0.58**
L_PRICE_ES_BS	1.43	7	**0.98**	L_PRICE_ES_OP	3.71	2	**0.16**	L_PRICE_ES_PK	7.32	9	**0.60**
All	11.49	14	**0.65**	All	5.28	4	**0.26**	All	22.52	18	**0.21**

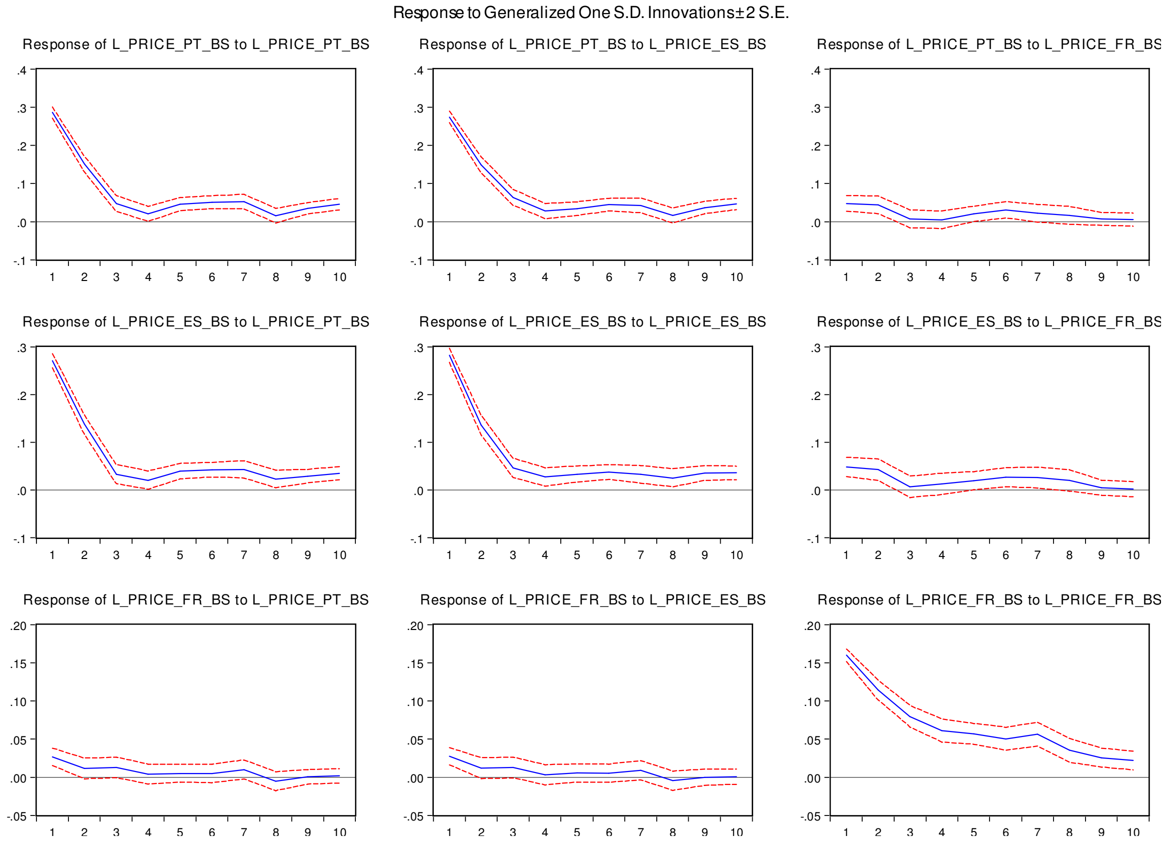

Figure 5 - Impulse response plots for daily-log base price models

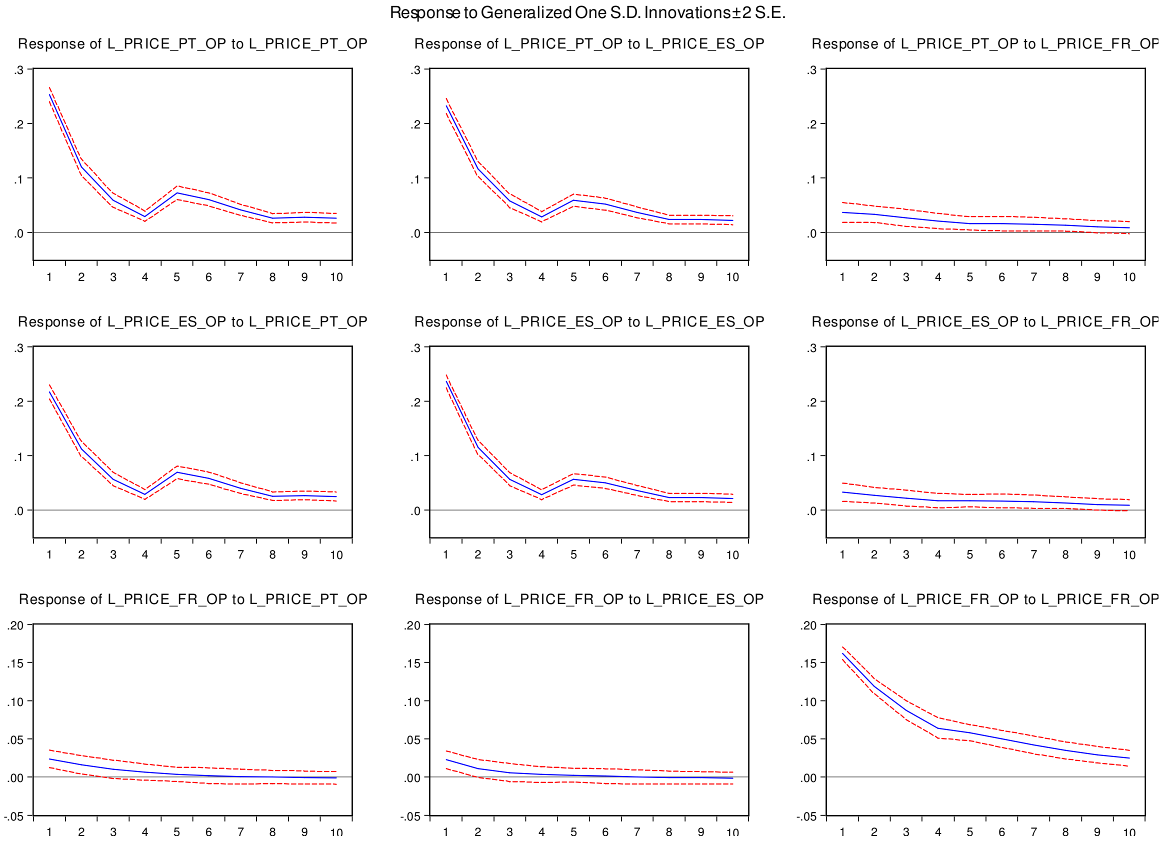

Figure 6 - Impulse response plots for daily-log off-peak price models

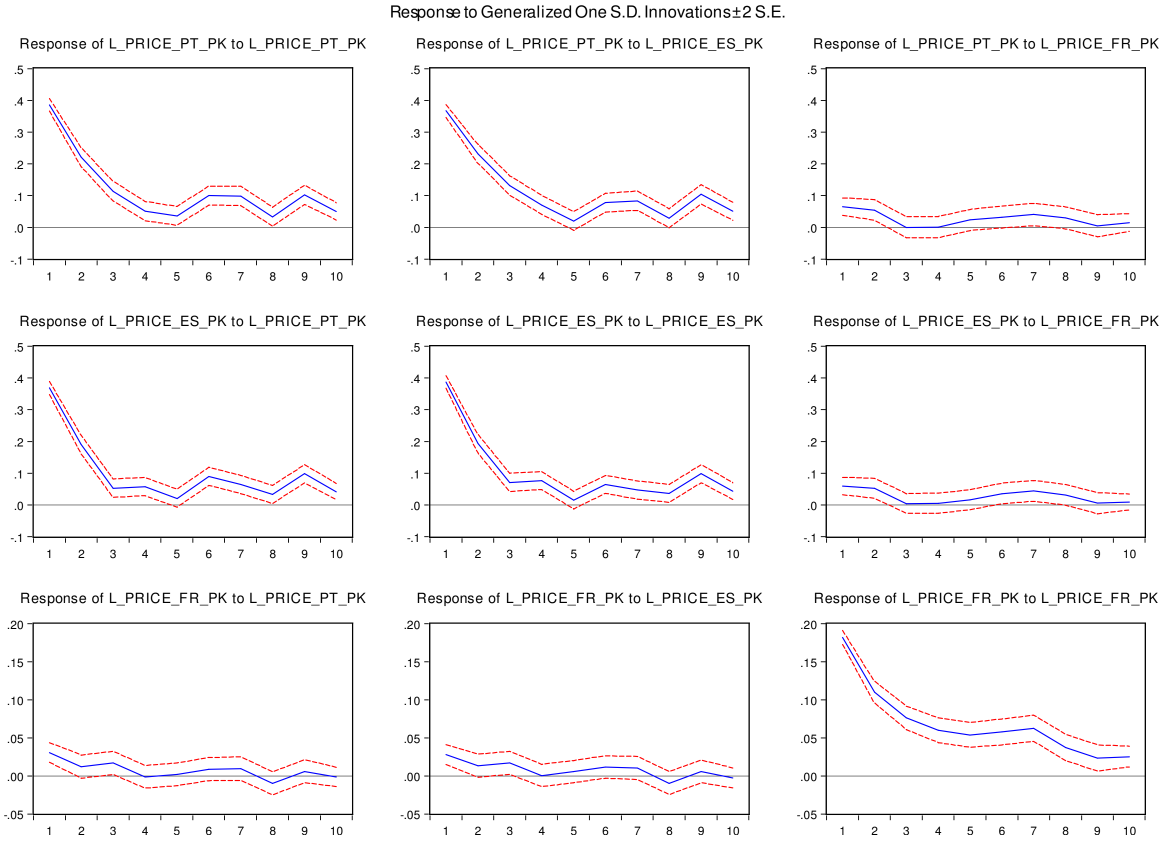

Figure 7 – Impulse response plots for daily-log peak price models

Final Remarks

The level of integration and some determinants on the South West Europe regional electricity market are evaluated in this study in order to assess the degree of accomplishment of the building of the European Internal market as aimed by the consecutive European Directives.

A future common competitive electricity market is aimed by European policy giving guidance to Member-State policy and statutes. The Electricity Regional Initiative was later on launched along this long process to attain the common electricity market. Simultaneously, the promotion of electricity generation by renewable energy sources was similarly an objective in Europe, reducing the dependency on imported fossil fuels and allowing GHG emissions mitigation. Large deployment of RES-E generation in Europe has been achieved through strong financial support mechanisms.

Results obtained from the model specification herein presented show that HDD contributed to a slight improvement to the model significance. Furthermore, it is to note that the introduction of the exogenous variable average wind speed improves all models specification.

The average wind speed both in Portugal and Spain show a significant negative influence for the Portuguese and Spanish base, off-peak and peak log-daily spot electricity prices. Regarding the French average wind speed, there is a significant negative contribution in all Powernext base, off-peak and peak log-daily spot electricity prices.

Strong integration was found between MIBEL markets, leading to the conclusion that the existing market setup is efficient and contributes to the integration of spot electricity markets. Also, as demonstrated by Grange-causality and impulse response analysis, there is a weak integration level between MIBEL and Powernext.

Findings in this article related with the impact of wind generation on interconnected markets are aligned with conclusions reached by several studies, albeit relying on a novel data and modelling approach. Results herein shown, highlight the importance of efficient electricity market design and effective renewable policies in facilitating RES-E penetration as in Klessmann et al. (2008), Milligan et al. (2009), Cruz et al., (2011) or Cutler et al., 2011. The significant negative contribution of wind speed on electricity spot market price does not mean that the electricity consumer price also decreases. As a matter of fact Silva and Cerqueira (2013) recently established a significant positive impact of 1,8% increase in consumer price for each 1% of RES-E. The incentives for the deployment of RES-E (Meyer, 2003) should be reviewed as it has been established to be in some cases a high burden on consumer electricity prices (Amorim et al., 2010; Sáenz de Miera et al., 2008), distorting the desired effect of the electricity spot market price decrease.

It is relevant to emphasize that in spite of the fact that the interconnection capacities available do not improve model specification *per se*, these are extremely important to transport the electricity generated by renewable sources and more specifically wind generation. The lack of sufficient interconnection capacity between France and Spain is likely to explain the non-significance of Spanish average wind speed on the French electricity market price. Additional work is currently being pursued to tackle this issue with more depth.

Having the current Internal Energy Market Directive aim as guideline, conclusions found in this study support that coupling and interconnection capacity expansion should be continuously sought between the French and Spanish electricity markets in order to achieve a full functioning South West Electricity regional market.

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