Integration and Convergence in European Electricity Markets

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INTEGRATION AND CONVERGENCE IN EUROPEAN ELECTRICITY MARKETS

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Abstract

In this paper we investigate wholesale electricity prices integration process in the main European markets. After reforms introduced in the last decades in Europe, wholesale electricity prices are now determined in regulated markets. However, while market institutional frameworks show several similarities, there are still differences in fuel mix, generation units technologies, market structure. Using multivariate cointegration techniques we test integration dynamics within four European markets (Austria, Germany, France and Italy) for which we have collected a novel dataset of spot prices from 2004 to 2010. We provide evidence that German market constitutes a common stochastic trend driving the long-run behavior of other markets. Our results are robust to causality test, to Granger causality test, to oil price relevance test and provide additional evidence to assess the efficient market hypothesis in European electricity markets.

Key words: European electricity markets, electricity spot prices, cointegration, structural MA representation.

JEL codes: C32, L16, Q41.

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1. Introduction

The liberalization process of electricity markets in Europe is more than a decade old, based on three steps (EU Directives in 1996 2003 and 2009), all with the common objective to push member countries to modify their national electricity markets architecture in order to achieve market integration[1].

The goal of market integration has been pursued promoting unbundling of existing vertically integrated companies, competitiveness in the wholesale generation capacity, free entry of new plants, creation of independent (or state owned) transmission system operator, increasing consumer choice possibility and regulation of trade across international inter-connectors (Pollitt, 2009). As highlighted by Green (2007), the first step represented a compromise that took in account heterogeneity in National electricity markets liberalization processes, while the second step focused on regulatory issues, such as creation of "independent national regulatory authorities" (Cornwall, 2008). Finally, the third package of directives is based on the results of an inquiry conducted by the Commission (EC 2006) throughout 2005-2006 that mainly showed that there exists excessive horizontal concentration in generation; excessive vertical integration between generation and transmission; insufficient interconnection among national grids (Trillas, 2010). During this relatively long period, former national monopolies have been broken up, antitrust measures have been enacted to attempt to spur competition, mergers and restructuring of big players in generations have taken place at the international level. In the meantime, fuel prices have rolled up and down and a major financial crisis has shocked financial and real markets. In this situation, it is interesting to ask whether national markets formerly dominated by a national monopolist have developed some form of interaction.

However, national electricity markets do not resemble financial markets, for they largely serve local needs. So interaction cannot be considered of the type prevailing in Stock Exchanges or other markets where paper assets are traded. However, it is undeniable that the large market restructuring which occurred in Europe has made more likely that decisions and price strategies are taken simultaneously on several markets, based on a common set of available information.

Thus, even if, from a physical viewpoint, the possibility to exercise time and space arbitrage in electricity markets is limited, it is conceivable that fuel price information available at the strategic decision center of one big multinational electricity generation company can be shared throughout its subsidiaries acting in different markets.

This gives rise to the idea that signaling may quickly spread around markets, even if these are physically separated; i.e. even if there are no relevant physical interconnections that allow a significant cross-border trade among countries, thus suggesting that efficient competition structure should prevail. On the contrary, despite EU and national regulatory efforts, there exists undeniable literature evidence that

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[1] The milestones of EU deregulation process in electricity market are the following. In 1996 a Parliamentary agreement was reached on market liberalization directive; in 1997 the Directive 96/92EC was enacted concerning common rules for the internal market in electricity; in 1999 there was end of the transposition period; in 2001 a directive was adopted on the promotion of electricity from renewable energy sources in internal electricity markets; in 2003 directive 2003/54 was adopted; in 2007 there was the publication of the results of a competition investigation criticizing the state of competition in the electricity sector; in April 2009 there was the enactment of the 3rd package of directives concerning electricity markets (2009/28).

organized electricity spot markets are far from the ideal competitive model. For instance, the Commission itself (EC 2007) admitted that the relevant market definition is national, as far as merger and acquisition rulings are concerned.

There exists a widely consensus on this point. Many scholars showed that there are quite different electricity market models in Europe[2], characterized by marked differences in terms of ownership type and degree of: openness, concentration, vertical integration, independence of authorities and unbundling effectiveness (network transmission, network distribution), along the electricity sector value chain.

In a comparative perspective, Glachant and Levêque (2009, p.3) warn that: *"The construction of the European Union's 'internal energy* [electricity included] *market' is still a work in progress. It might even stall."*

Given this situation, we know that in a competitive model price formation should be primarily influenced by international fuel price fluctuations and that in non competitive markets other behaviors and shocks may influence price formation (ranging from international fuel price, to local weather conditions, and to local market power behavioral shocks). For these reasons, we avoid the idea of testing market efficiency (Lu et al., 2005) or of testing EU policies success, i.e. that electricity markets are evolving consistently with the European Commission projects (Bosco, et al. 2010, Pelagatti et al., 2007).

Given that theoretical competitive market designed by EU in reality does not exist, every conclusion in favor of integration is bound to be false, because we know that there is not a competitive market. Alas, every conclusion against integration is tautological, because we know already that there is not a general competitive market in Europe.

For similar reasons, even if it is true that fuel price fluctuation should largely influence electricity prices trading in the market place, strategic bidding behaviors can provide countless reasons for obscuring the existence of a stable correlation between the fuel market prices and the electricity market prices.

Based on previous considerations, the primary focus of this paper is to investigate whether there exists some information signaling among different European, rather than to investigate the existence of a structural relationship between fuel prices and electricity prices. In this respect, we adopt a weak assumption on market behavior, for we simply assume that it is rational for suppliers and buyers to adjust their behavior according to available information. Given the previous rather weak assumption, it is efficient for a rational agent to process and incorporate information in his own decision mechanism, taking into account all relevant information available.

In this paper we use hourly data about four European electricity pool markets: Austria, Germany, France and Italy for the 2004-2010 period. In this paper, we explore the degree of integration among four electricity pool markets utilizing Johansen's (1995) maximum likelihood (ML) extension of the Engle and Granger (1987) cointegration framework.

The paper is organised as follows. In Section 2 the empirical framework is outlined. Section 3 presents data and preliminary analysis. In Section 4, results from dynamic simulations based on forecast variance decomposition are discussed. Some final remarks follow in the concluding Section 5.

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[2] An exhaustive review of these differences is available in Erdogdu (2010).

2. The empirical framework

In the last years, many scholars have focused on the restructuring process in the European Electricity market. Considering only spot markets, the main topics investigated are prices convergence (among others Zachmann, 2008), prices dependence (Lindström and Regland, 2012), integration (among others Bunn and Gianfreda, 2010), cross-border integration (among others Balanguer, 2011; Cartea and Gonzàlez-Pedraz, 2011) and corporate concentration (among others Thomas, 2007; 2009). Furthermore, prominent researchers have analyzed the whole liberalization and integration process (see among others Glachant and Levêque 2009; Politt, 2009).

A large part of this empirical literature agrees on the incompleteness of the integration process in European electricity markets. Nevertheless, some authors underline the existence of some positive results. Firstly, evidence of convergence and dependence in spot market prices can be detected if off peak hours and/or days are considered. For instance, Zachman (2008) shows that 59% of the analyzed hourly pairs of national wholesale electricity prices converged in the period 2002-2006, especially in off peak periods. Among the several countries analyzed by Zachman, Germany seems the most integrated market with a high correlation with the French market (ibidem, p. 1666). More recently, Lindström and Regland (2012, p. 13), analyzing only extreme events, find that in term of pair wise dependence between markets dependence varies from almost independent to strongly dependent and that dependence is not symmetric. In particular German Market is regularly co-spiking (upward movements) with all markets (French included) except the Scandinavian one and (ibidem, p. 12): *"[it] has a large conditional probabilities of experiencing downward movements when a neighboring market also experiencing the same event."* The crucial role played by German market is also underlined by Bunn and Gianfreda (2010, p. 285). They find evidence of high integration in shock transmission among German market and other ones.

Another relevant aspect concerns the corporate analysis in term of competitive positions. In its frequently reports Thomas (2007, 2009) highlights that among the *"Seven Brothers"* (Thomas, 2003) E.ON -Endesa, EDF and Electralabel play a crucial role in several markets[3]. The pervasive presence of the major companies in several markets could determine both high concentration ratio and strategic interaction in different markets that can lead to anticompetitive behaviour.

We start addressing the question of whether European electricity market have experienced convergence patterns in the last years. According to stochastic definitions of convergence and common trends based on cointegration analysis of Bernard (1991), a necessary (but not sufficient) condition for convergence among countries and/or markets is that there be *n-1* cointegrating vectors for a sample of *n* countries or markets. Thus, we use a multivariate specification for the system of *n* electricity spot prices equations according to a Vector AutoRegressive (VAR) process of order p

$$\mathbf{y}_t = \sum_{l=1}^{p} \mathbf{A}_l^y \cdot \mathbf{y}_{t-l} + \boldsymbol{\varepsilon}_t \tag{1}$$

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[3] In particular E.ON-Endesa is "home market" in Germany and Spain and it has "significant holdings" in UK, Italy, Benelux and Nordic market. EDF is "home market" in France and has "significant holdings" in UK, Germany and Italy while Electrabel is "home market" in France and Benelux and has "significant holdings" in Italy and limited in Germany (Thomas, 2007).

where y_t is a n-dimensional vector of electricity prices. Equation (1) can be represented in its isomorphic Vector Error Correction (VEC) form:

$$\Delta\mathbf{y}_t = \mathbf{\Pi}^y \cdot \mathbf{y}_{t-1} + \sum_{l=1}^{p-1} \mathbf{P}_l^y \cdot \Delta\mathbf{y}_{t-l} + \boldsymbol{\varepsilon}_t \qquad , \qquad \boldsymbol{\varepsilon}_t \sim N\left(\mathbf{0}, \mathbf{\Sigma}_\varepsilon\right) \tag{2}$$

where $\mathbf{\Sigma}_\varepsilon$ is the time-invariant variance-covariance matrix associated to the vector of residuals $\boldsymbol{\varepsilon}_t$. VEC modelling builds on the association between the economic concept of long-run and the statistical concept of stationarity and focuses on the identification of stationary linear combinations of the data, known as cointegration vectors. In the presence of cointegration $\mathbf{\Pi}^q$ has reduced rank $r<n$ and can be decomposed as $\mathbf{\Pi}^q = \boldsymbol{\alpha} \cdot \boldsymbol{\beta}'$, where matrix $\boldsymbol{\alpha}$ contains the feedback coefficients (loadings) and matrix $\boldsymbol{\beta}$ contains $r<n$ theory-based long-run relationships to which the series converge, once all the effects of transitory shocks have been absorbed (Johansen, 1995). These cointegrating relationships are hit by $n-r$ permanent shocks (the common trends). Rank of matrix $\mathbf{\Pi}^y$ allows to identify different long-run equilibrium path for the electricity prices. If all elements of vector $\mathbf{y}_t$ are unit root processes, the rank of matrix $\mathbf{\Pi}^y$ will be equal to zero and in this case will be impossible to identify a long run equilibrium condition among electricity prices. In any intermediate result with a reduced rank of matrix $\mathbf{\Pi}^y$ we can identify a long run representation of the integration process between markets.

3. Data and preliminary analysis

3.1. Data description and unit root analysis

For the empirical analysis we employ data registered in four European wholesale markets, EXAA (Austria), EEX (Germany), Powernext (France) and IPEX (Italy) for hourly time series of spot electricity prices[4], labelled: AU, DE, FR, IT. All prices are expressed in €/MWh. These markets share similar marginal generation technology but differ in generation fuel mix, as shown in Table 1; in Italy generation capacity is skewed toward hydrocarbons, oil and gas, which cover more than 70% of total production; in Germany coal and nuclear satisfy more than 2/3 of electricity generation capacity. In Austria hydropower has 63% share and in France nuclear power has 75% share of generation mix. As far as interconnection is concerned, Germany is well linked with Austria and France. Italy and France are rather less linked as well as Italy and Austria. Thus, Italy is the less integrated country (Creti et al., 2010). Furthermore, since 2010, Germany, France and Austria have implemented a price and volume market coupling arrangement with the Netherlands.

We compute hourly daily price change as the difference in (logs of) spot prices registered in the same hour between two consecutive days. As it is well known electricity cannot be stored, e.g. inventories cannot be used to arbitrage prices across over time.

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[4] Data source is Data Stream for DE, AU and FR while Italian data are freely available on GME web site (http://www.mercatoelettrico.org/En/Tools/Accessodati.aspx?ReturnUrl=%2fEn%2fStatistiche%2fME%2fDatiSintesi.aspx). For gas and oil we use the Zeebrugge Natural Gas series and the London Brent Crude Oil Index, respectively.

Table 1 - Fuel mix electricity generation (GWh and %) year 2009

Production from:	Austria		Germany		Italy		France	
- coal and peat	5032	7.294%	257137	43.401%	43416	14.836%	28708	5.295%
- oil	1137	1.648%	9639	1.627%	25946	8.866%	6170	1.138%
- gas	12338	17.884%	78884	13.315%	147269	50.324%	21013	3.876%
- biofuels	4003	5.802%	25928	4.376%	6015	2.055%	2125	0.392%
- waste	796	1.154%	9634	1.626%	3388	1.158%	3960	0.730%
- nuclear			134932	22.775%			409737	75.572%
- hydro*	43662	63.288%	24710	4.171%	53443	18.262%	61912	11.419%
- geothermal	2	0.003%	19	0.003%	5342	1.825%		
- solar PV	35	0.051%	6579	1.110%	676	0.231%	171	0.032%
- solar thermal								
- wind	1967	2.851%	38639	6.522%	6543	2.236%	7891	1.455%
- tide							497	0.092%
- other sources	17	0.025%	6363	1.074%	603	0.206%		
Total Production	68989		592464		292641		542184	

Source: International Energy Agency.

Thus, the main empirical finding is that spot prices are characterized by volatility, extreme values and seasonality. Prices distribution is bimodal with two different peak periods: hours between 11-12 and 18-20. With this type of distribution we deem impossible to use a daily positional index in order to fully take in account the real data generation process and, consequently, we think that econometric analysis could be biased, partial and limited. Italian IPEX is characterized by values structurally higher if compared with other markets. On average, Italian prices exceed others by 30-50% for each hour of the day but they are characterized by a smaller range of price variation. Indeed in the other three markets prices have occasional spikes and go up over the 500 Euro/MWh threshold, while this doesn't occur in Italy. Some descriptive statistics used in the econometric analysis are shown in table 2.

Table 2 – Descpriptive statistics

	DE	AT	FR	IT
Mean	3.75	3.78	3.79	4.20
Median	3.71	3.73	3.74	4.22
Maximum	5.05	4.99	5.05	4.92
Minimum	0.07	2.51	2.04	0.16
Std. Dev.	0.42	0.41	0.44	0.30
Skewness	-0.25	0.13	-0.07	-2.22
Kurtosis	5.56	2.90	3.21	25.76

The objective is to determine whether the close proximity and integration of the electricity markets result in significantly different price convergence in the long run. If so, there is evidence that electricity market integration and convergence in the EU occurred. As a preliminary exercise, we test for unit root behaviour of each of the four series. ADF (Dickey and Fuller, 1979) tests both in levels and first differences[5]. In each case (Table 3), we are unable to reject the unit root-null hypothesis at conventional

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[5] Critical values for these tests are provided by MacKinnon (1996). A constant term is included in each regression, while the number of lags is chosen such that no residual autocorrelation is evident in the auxiliary regressions. We have also carried out alternative unit root tests (Philips and Perron, 1988 and Kwiatkowski et al., 1992) to check for robustness. The results are qualitatively similar (available from the authors upon request).

nominal levels of significance and when we take the first difference we find evidence of stationarity in the series.

Table 3 – Unit Root Tests

ADF tets	DE	AT	FR	IT
Deterministic part	C	C	C	C
Test statistics	-2.75	-2.76	-2.64	-2.62
	ΔDE	ΔAT	ΔFR	ΔIT
Deterministic part	-	-	-	-
Test statistics	-55.79	-51.66	-56.89	-57.55

Note. Statistics are augmented Dickey–Fuller test statistics for the null hypothesis of a unit root process; DE, AT and IT denote the log level of electricity spot prices for Germany, Austria, France and Italy, respectively. Δ is the first difference operator. The critical value at the 1% level of significance is –3.57 to two decimal places if there is a constant (c) in the regression, and -2.61 if no deterministic components are included in the regression, while at the 5% level of significance these values are -2.92 and -1.95, respectively (MacKinnon, 1996).

Thus we find evidence that each of the electricity series has a unit root (or a stochastic trend) in its univariate time series representation. The next step is to consider the multivariate rapresentation of these series and test whether there are common stochastic trends. From an empirical point of view, given the evidence of *I(1)-ness* for all individual electricity spot market prices, testing for cointegration among them is the logical next step.

3.2. Model specification and cointegration tests

We estimate equation (2) with n= 4 (AU, DE, FR, IT) with a two-step strategy. Firstly, the lag length p is chosen so estimated residuals resemble the multi-normal distribution as closely as possible, this being an essential requirement for a correct statistical inference.

Secondly, the long-term component of the model is identified on the basis of the trace test and the maximum eigenvalue test (Johansen, 1995). The general-to-specific procedure, with maximum order of autoregression set to 36, suggests choosing $p=22$. The results of the main univariate (Table 4, Panel a) and multivariate (Table 4, Panel b) diagnostic tests indicate that estimated residuals match the multi-normal distribution in a satisfactory way both at single equation and system level.

In table 5 trace and maximum eigenvalue test statistics suggest the presence of three cointegration relationships in the system at the 5 percent significance level[6]. In the rest of the table exclusion, stationary and weakly exogeneity tests are reported. Testing separately the null hypothesis of each coefficient being equal to zero leads to null rejection [Panel (b)]. Furthermore, none of the variables is stationary in the cointegration space, as shown by the univariate unit root and stationarity tests [Panel (c)].

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[6] The choice of the cointegration rank is also robust to a graphical analysis of the recursive trace tests. Since the trace statistic is given by $-T_j \ln(1-\lambda_i)$, with $j = T_1,..., T_t$, it grows over time as long as $\lambda_i \neq 0$, while must be constant If $\lambda_i \to 0$. The first *r* trace statistics should grow linearly, while the other ones must be constant over time. The graph shows that the first three statistics grow linearly as expected, while the fourth one is less clearly increasing (graphs for recursive trace test statistics are available upon request).

Finally, only in the case of German price equation there is a clear evidence of weakly exogeneity. Therefore, we can consider this equation as the common stochastic trend of the system [Panel (d)].

Table 4 – Misspecification tests

(a) Univariate misspecification tests

	DE	*AT*	*FR*	*IT*
AR	1.5911 [0.1463]	1.1532 [0.3363]	0.5849 [0.7668]	0.3374 [0.9351]
Normality	3.4745 [0.1760]	4.0960 [0.1290]	1.1350 [0.5669]	16.108 [0.0003]
ARCH	0.9031 [0.5075]	1.1315 [0.3500]	1.5206 [0.1694]	5.1289 [0.0001]
Heteroscedasticity	0.5027 [0.9936]	0.6682 [0.9278]	0.8185 [0.7687]	0.6991 [0.9027]

(b) Multivariate misspecification tests

AR	1.1765 [0.1397]
Normality	13.024 [0.1110]
Heteroscedasticity	0.5572 [1.0000]

Note: p-values in square brackets

Table 5 – Cointegration analysis

(a) Cointegration rank

			Trace test		Maximum eigenvalue test	
p-r	R	Eigenvalue	Statistics	95% cv	Statistics	95% cv
4	0	0.0359	138.279	40.175	78.250	24.159
3	1	0.0182	60.029	24.276	39.474	17.797
2	2	0.009	20.554	12.320	20.547	11.225
1	3	0.000	0.008	4.130	0..008	4.130

(b)Test of exclusion

r	dgf	5% .v.	*DE*		*AT*		*FR*		*IT*	
3	3	7.815	69.601	(0.000)	68.726	(0.000)	33.561	(0.000)	19.986	(0.000)

(c)Test of stationarity

r	dgf	5%c.v.	*DE*		*AT*		*FR*		*IT*	
3	1	3.841	9.848	(0.002)	10.090	(0.001)	8.656	(0.003)	11.420	(0.001)

(d) Test of weak exogeneity

r	dgf	5%c.v.	*DE*		*AT*		*FR*		*IT*	
3	3	3.841	5.678	(0.128)	7. 923	(0.048)	12.968	(0.005)	16.377	(0.000)

Note:(a) The critical values for trace test and maximun eigenvalue statistics are from Pesaran and Shin (2000); (b) p-value in round brackets.

3.3. Testing market integration in the long run

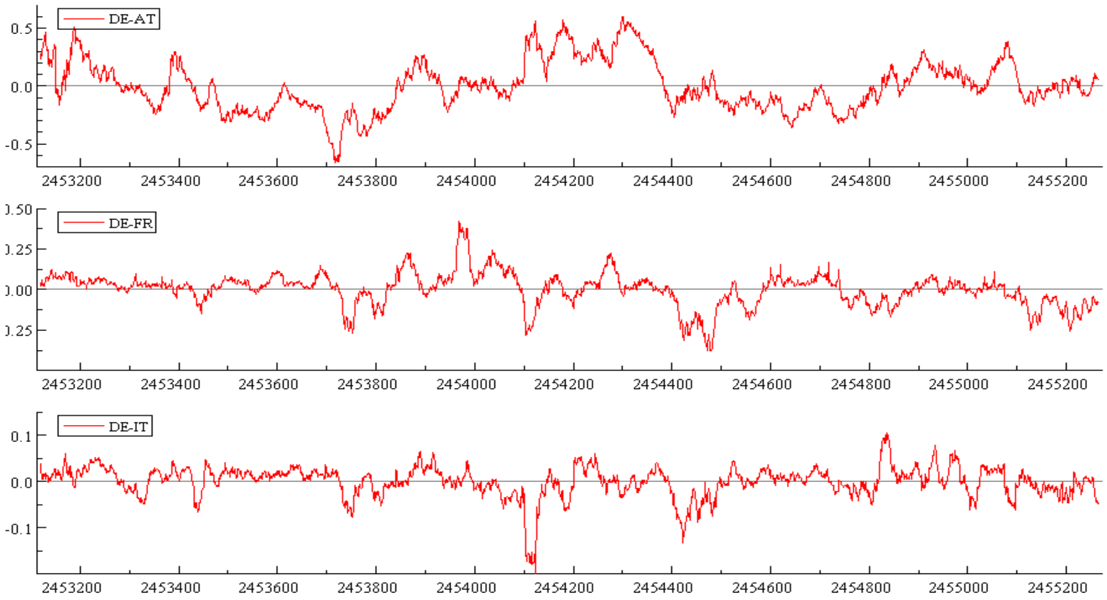
We proceed to establish whether the cointegration vectors can be identified in terms of the structure which indentifies a framework of general bilateral integration between markets. In particular, we want to test a set of restrictions in the cointegration space of the form:

$$\beta' y_{t-1} = \begin{bmatrix} 1 & -1 & 0 & 0 \\ 1 & 0 & -1 & 0 \\ 1 & 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} DE_{t-1} \\ AT_{t-1} \\ FR_{t-1} \\ IT_{t-1} \end{bmatrix} \tag{3}$$

This representation implies three different bilateral integration processes between Germany market (the common trend) and the other ones. Using a standard χ^2-distributed LR ratio test with 3 degrees of freedom, the test statistics (5.925) indicate that the restrictions are not rejected by the data at the usual significance levels (p-value of 0.115). We also test for Granger-Causality in the whole system in order to verify if DE-prices "Granger-cause" the other variables in the model. Thus, we perform the usual F-test on the significance of lagged values of DE in the equations of AU, FR and IT. Under the null hypothesis "DE" does not Granger-cause "AU, FR, IT", rejection of the null confirms that DE cause “AU, FR, IT" [test statistic $_1$ = 1.6592; pval-F(l; 57, 8264) = 0.0014]. Finally, we also perform a test for instantaneous causality, concluding that there does not exist instantaneous causality between “DE" and “AU, FR, IT“ [Test statistic: χ = 828.0805 *pval-Chi*(χ;3)=0.0000].

We compute a restricted R-model[7], whose cointegration relationships are depicted in Figure 1.

Figure 1 – The cointegration vectors from the R-model



Note. The plots of cointegration vectors are from the R-model. It is computed estimating the ECM representation of the system deleting all dummies and the short-run dynamics. The result is a model where only the long-run properties of the data are isolated.

There appears to be a clear cointegrating relationship in all three cases. Then, we analyze the long-run properties of system (3), studying their persistence profiles (Pesaran and Shin, 1996), in order to assess how long the system takes to revert to its steady state path, after being hit by a system-wide shock. By construction these profiles should tend to zero as the number of simulation periods increases only if a cointegration vector analysed is genuinely stationary, while in the case of *I(1)* (or “near integrated”) series these can be different from zero for a long period.

We simulate over a 5 years horizon the absorption path of deviations from the bilateral equilibrium relationship between each European market (AT, FR, IT) and the German one, as shown in Figure 2[8].

In all cases, convergence towards the steady-state follows a decreasing trajectory, with adjustments from disequilibrium ending within the fifth year. The half-life of the deviation from the steady-state is close to five months, even if it seems to be higher for Italy.[9]

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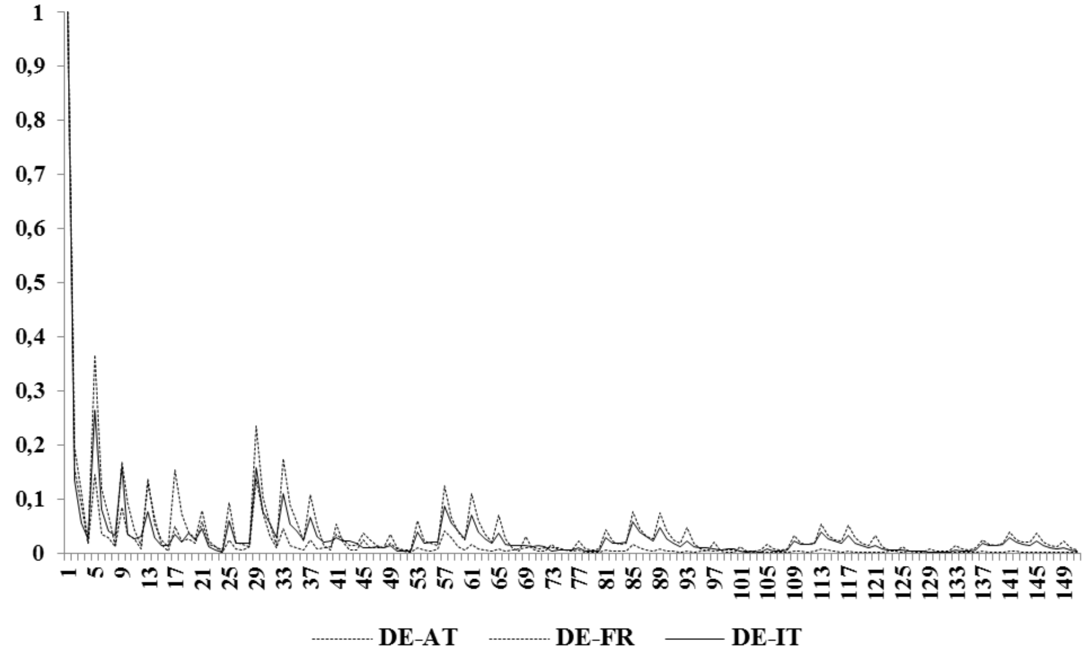
[7] The R-model is computed estimating the VEC representation of the system deleting all dummies and the short -run dynamics. The result is a model where only the long-run properties of the data are isolated (Johanesen, 1995).

[8] The size of all the shocks analyzed in this section is set equal to one standard deviation.

[9] Half-life is defined as the number of months after which the deviation from the steady-state falls to half the size of the initial shock.

Figure 2 – Persistence profile of cointegration vectors



Note. The vertical axis indicates the magnitude of the deviation (normalized to unity on impact) from the steady-state level. The horizontal axis measures the number of months after the shock. Simulation horizon is equal to 5 months.

3.4. Robustness: oil price relevance

The identification of the cointegration space described in the previous section allows interpreting the three long-run relations as convergence patterns between each national electricity price and the German one. We want to check the robustness of this key result, introducing into the original system information about energy input prices. In particular, we estimate a new VAR model in which we control for oil prices. We expect that the identification of the cointegration space should remain the same, if signaling process from German to "regional" markets is robust. Otherwise, in the presence of a "weak" signaling relation between markets, introduction of oil prices could lead to a different system representation, with a smaller role played by Germany's electricity price. Cointegration tests for the model augmented by oil prices are shown in Table 6.

Table 6 – Robusteness: the role of Oil prices

			Trace test		Maximum eigenvalue test	
p-r	r	Eigenvalue	Statistics	95% cv	Statistics	95% cv
5	0	0.0367	157.637	60.061	80.197	30.440
4	1	0.0189	77.440	40.175	40.946	24.159
3	2	0.0104	36.494	24.276	22.484	17.797
2	3	0.0064	14.009	12.321	13.684	11.225
1	4	0.000	0.325	4.130	0.325	4.130

Note:(a) The VAR model cointains the original electricy price time series (Germany, Austria, France and Italy) plus Oil prices. We allow for a lag length of 22 (in the levels) and an unrestricted constant term in the VECM specification. The critical values for trace test and maximun eigenvalue statistics are from Pesaran and Shin (2000).

Both trace and maximum eigenvalue test statistics suggest the presence of four cointegrating vectors. We assume that this new long-run relations depends on the oil prices behavior[10] and, therefore, we test the scheme (1) in order to verify if the first three long-run vectors in this new model satisfy the [1;-1] restrictions implied by our identification strategy. The χ^2-distributed LR ratio test with 4 degrees of freedom (test statistics equal to 7.068, p-value of 0.132) indicates that these restrictions are not rejected by the data. The scheme that identifies three different long-run integration patterns between each electricity market and the German one is still valid even when we control for the influence of oil prices in the system[11].

3.5. Modelling the structure of the α matrix

The short-run dynamics of model is modelled using a parsimonious (subset) VEC model, obtained dropping those parameters in the model with p-values lower than a significance threshold,[12] according to the Sequential Elimination of the Regressors Testing Procedure (SER/TP) proposed by Brüggemann and Lütkepohl (2001). Specifically, the statistically significant parameters of α matrix give useful information about how national market models move around the long-run equilibrium path. Table 7 reports the coefficients estimated by 3SLS only for the α matrix[13]. The analysis of the elements of the loading coefficients matrix allows highlighting some interesting results. The equations ΔAT, ΔFR and ΔIT are obviously affected by the cointegration residuals which identify the long run convergence equilibrium between each market and the German system. Moreover the (absolute) values of the feedback coefficients indicate that adjustment speed towards equilibrium is higher for Austria. Finally, there is evidence of some influence of the three cointegration vectors (namely $\varepsilon_1, \varepsilon_2$ and ε_3) on other market equations.

Table 7 – VECM model estimated by 3SLS- The long run

	ΔDE	ΔAT		ΔFR		ΔIT	
$\varepsilon_{1,t-1}$	.	-0.725	(0.035)	-0.084	(0.043)	.	
$\varepsilon_{2,t-1}$	.	0.122	(0.018)	-0.248	(0.021)	-0.078	(0.020)
$\varepsilon_{3,t-1}$	.	-0.064	(0.013)	-0.071	(0.006)	-0.365	(0.019)

Notes. Standard errors in round brackets. $\varepsilon_1, \varepsilon_2$ and ε_3 are the three cointegration vectors.

Overall, this means that even if we are able to identify bilateral equilibrium conditions for each electricity market *versus* the German one, our model allows also for spill-over effects between markets. Therefore, even if in our model the German dynamics drives the integration process, there are also other interesting relationships between other counties which characterized the European electricity markets convergence process.

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[10] This result is consistent with the evidence provided by Bosco et al. (2010), where a long-run relation between electricity and oil prices is detected.

[11] Moreover we test for the joint hypothesis of weakly exogeneity of both German electricity prices and oil prices. The statistics suggest that both variables are weakly exogenous with respect the cointegration space (LR test of restrictions: χ^2 (3) =4.8150 [0.1859]).

[12] The AIC criterion with $t = 1.60$ is used as a significance threshold level for short-run parameters. This is motivated by the idea that, in the reduction process of the model, it is preferable to keep the coefficients whose statistical significance is unclear.

[13] The other coefficients are not reported, but are available under request.

4. Dynamic simulation: the role of global and regional shocks

In this section we move from a reduced-form to a structural representation of the multivariate time-series model so as to ascertain the role of global and regional (idiosyncratic) shocks hitting the European electricity markets considered. We employ the forecast error variance decomposition (FEVD) tool, which aims at providing information on the relative importance of the forecast error variance of each shock as a function of the simulation horizon. The reduced form residuals in model $\mathbf{u}_t$ and the structural residuals $\mathbf{v}_t$ are linked through the relationship $\mathbf{u}_t = \mathbf{B} \cdot \mathbf{v}_t$, where $\mathbf{B}$ is a non-singular matrix (Warne, 1993). Retrieving v's from u's implies the unique determination of the $n^2=16$ elements in $\mathbf{B}$. In our identification scheme, a first set of 10 constraints arises by assuming that structural shocks are orthonormal. Choosing the cointegration produces $r(n-r)=3$ additional restrictions and allows to distinguish transitory shocks (three in our case) from permanent (one) innovations. The remaining three restrictions are obtained by imposing a recursive scheme in the transitory shocks matrix in which the variables causal order is chosen according to the estimated adjustment coefficients size. Thus, the causal order is the following: Austria, France and Italy.

The permanent shock is derived from the system common trend (i.e., its permanent component) and represents the global-external shock that hits in a symmetric way all markets. By contrast, transient impulses hit in an asymmetric way each country according to their different degree of interdependency. Furthermore, temporary shocks are aggregated so as to quantify the overall relevance of regional factors in explaining electricity price fluctuations.

Table 8 shows the percentage of the variance of each variable of the system explained by the four shocks: global (Germany) and regional ones (Austria, France and Italy). The last column (mean) presents the shocks average contribution over the entire simulation spans (60 months). As can be seen, the German market shock (the global one) is the main driving force of electricity movements, confirming our interpretation of the symmetric signalling shock hitting other markets price formation. In particular, about 80% of forecast variance of Austrian electricity price is explained by global shock. This percentage in equal to 78% and 71% for France and Italy prices, respectively.

Table 8 – Forecast error variance decompositions

	ΔAT	*ΔFR*	*ΔIT*	Mean
Global shock (DE)	*79.91*	*78.03*	*71.40*	*76.45*
Regional shock (AT)	2.54	1.33	0.98	1.59
Regional shock (FR)	15.63	18.71	13.19	15.68
Regional shock (IT)	1.92	1.93	14.43	6.28

Note. The permanent shock is associated to the common trend of the system (that is the German electricity spot price) and represents the global-external shocks that hit in a symmetric way the other markets. Individual temporary shocks identify idiosyncratic disturbances. The figures represent the percentage of the variance of each variable of the system explained by global and "regional". The last column (mean) presents the average contribution of the shocks over the entire simulation period (60 months).

With respect regional shocks, it is possible to note that the "domestic" shock in France accounts for about 18% of forecast variability of French electricity price. This percentage is larger than those shown by other countries (2.5% and 14.2% for Austria and Italy respectively) and confirms the relatively higher degree of exogeneity of

French electric system, which can be easily explained by the greater importance of nuclear technology in French electricity generation mix.

5. Conclusions

In this paper we have estimated a model to test integration and convergence among four European electricity markets. Our identification strategy allows to verify the presence of three different long-run equilibrium conditions between the German market and Austrian, Italian and French ones, respectively.

The main empirical evidences are as follows. German market behavior appears as the common trend for other regional markets, thus providing signaling information. This can be explained in two ways: (i) DE is the largest market in Central Europe and it is taken as a reference; (ii) pricing in electricity markets is dominated by peak-load plants, which typically exhibit CCGT technology (i.e. gas fired) and gas marginal price is largely influenced by German market operators.

The speed of adjustment towards equilibrium and the degree of convergence is higher for Austria. Persistence appears to be higher in FR. This is no surprise, given that the French electric system is the most un-flexible (because of its very high nuclear share).

These results seem robust even when we control for oil prices in the system and the identification scheme obtained in the baseline specification is confirmed.

Forecast error variance decomposition analysis shows that the Italian market is the market with lowest share of global shock compared to other countries. Thus the signaling effect of global shocks in price formation is the least important in the Italian case.

The fact that roughly 1/4 of FEVD is not explained by a global shock (which can be typically thought as a fuel price shock) indicates that there are other factors, like specific fuel mix and/or non-competitive strategic behavior, influencing equilibrium prices, which motivates future research.

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