INTEGRATION AND CONVERGENCE IN EUROPEAN ELECTRICITY MARKETS

Carlo Andrea Bollino[a,c] - Davide Ciferri[b] - Paolo Polinori[a]

[a] *Department of Economics, Finance and Statistics - University of Perugia (I) Via Pascoli 20, 06123, Perugia;*
[b] *Cassa Depositi and Prestiti SpA;* [c] *LUISS, Guido Carli.*

E-mail of corresponding author: davideciferri@gmail.com

ABSTRACT

In this paper we investigate the potential integration in the wholesale electricity prices of the main European markets. After the reforms introduced in the last decades in Europe , wholesale electricity prices are now determined in regulated markets. However, while the market frameworks show several similarities, there are still differences in the composition of the generation units as well as in the technologies adopted. Using multivariate cointegration techniques we test the integration dynamics within four European markets (Austria, Germany, France and Italy) for which we have collected a novel dataset of daily spot prices from 2004 to 2010. We provide evidence in support of a common stochastic trend driving the long-run behavior of European electricity markets. Thus, our results 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.*

1. Introduction[1]

The liberalization process of electricity markets in Europe is more than a decade old. In the past years, three EU Directives in 1996 2003 and 2009 have dealt with the objective to design common measures to be taken by member countries in order to modify the entire architecture of their national electricity markets. Specifically, these are Directive 96/92, Directive 2003/54 and Regulation 1228/2003 and Directive 2009/28[2].

Pollitt (2009), among others, widely discussed the first two steps of the European reform underlining some key elements: in detail (*ibidem, p. 14*) he referred on the role of unbundling vertically integrated company, competitiveness in the wholesale generation capacity, free entry of new plants, the presence of a independent (or state owned) transmission system operator, possibility of choice in final supply market and regulation of trade across international inter-connectors. As highlighted by Green (2007), the first step represents a compromise that took in account heterogeneity among countries in term of degree of liberalization of National electricity markets while the second step of the reform focused on regulatory issues, such as the 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 exist excessive horizontal concentration in

[1] A preliminary version of this paper was presented at the: XIX International "Tor Vergata" Conference on Money, Banking and Finance "New Frontiers of Banking and Finance after the Global Crisis", Rome, December 13-17, 2010 University of Tor Vergata, Faculty of Economics; 30th USAEE/IAEE North American Conferences: "Redefining the Energy Economy: Changing Roles of Industry, Government and Research"; October 9-12, 2011; WASHINGTON, DC; 34th IAEE International Conference -Institutions, Efficiency and Evolving Energy Technologies- Stockholm, June 19 - 23, 2011; we are indebted to all participants. The authors are also thankful to Paolo Bruno Bosco, Paolo Falbo, Lucia Parisio, Matteo Pelagatti, Silvana Stefani; and to all participants at the: Final Conference (PRIN 2007) "Real structure and empirical models of the Italian electricity market: an analysis for the design market transfer to the South Eastern European countries" Milano Bicocca, June 28, 2011 for their helpful suggestions and remarks. The usual disclaimer applies. *The views expressed in this paper are our own and do not necessarily reflect those of Cassa Depositi and Prestiti SpA.*

[2] 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 to the electricity markets (2009/28).

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 the former national markets dominated by the national monopolist show now 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 allows a significant cross-border trade among countries, thus suggesting that efficient competition structure should prevail. Nevertheless, notwithstanding all the repeated efforts put in place by national governments, regulators and the EU, there is large accumulated evidence in the literature that organized electricity spot markets are far from the ideal competitive model. For instance, we find that the Commission (EC 2007) itself has taken the position that the relevant market definition is the national one, as far as merger and acquisition rulings are concerned, reporting that the broadening of national electricity markets is uncertain and not likely to be achieved in the short term.

There exists a widely consensus on this point. Many scholars showed that there are quite different electricity market models in Europe[3], characterized by marked differences in terms of degree of openness, degree of concentration and vertical integration but also in terms of ownership type, degree of independence of authorities and degree of

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

unbundling effectiveness (network transmission, network distribution, ...) along the chain value of the electricity sector.

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 current, political, institutional and business conditions in Europe, there are non guarantees that the dynamics of the constructions will not dissipate, as in U.S., or that the internal market will not fracture into 'national blocks' that might be permanent or persist for a long time."*

In this context, the relevant issue here is that in a competitive model, price formation should be primarily influenced by international fuel price fluctuations. However, in non competitive markets all sorts of behaviors and shocks may influence price formation in those markets, ranging from international fuel price, to local meteo conditions, and to local market power behavioral shocks. In this respect, we deliberately want to avoid such ideas like testing the success of EU policies, i.e. that electricity markets are evolving consistently with the European Commission projects (Bosco, et al. 2010, Pelagatti et al., 2007) or the idea of testing market efficiency (Lu et al., 2005), for the following reasons.

EU architecture aims at a theoretical competitive market, which in reality it is known that it does not exist. So 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 the 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 the previous considerations, in this paper we do not want to investigate a structural relationship between fuel prices and electricity prices, but we rather want to investigate whether there exists some information signaling among different European markets.

In this respect, we think that we are setting forth a weaker 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, we think that for a rational agent the most efficient way to process and incorporate information in his own decision mechanism is to take into account all relevant information available. So we consider at the same time natural and necessary to use the entire dataset about the hourly price setting.

In this paper we use data about four European electricity pool markets: Austria, Germany, France and Italy for the 2004 2010 period.

We think that any data manipulation has to be explicitly justified, when dealing with electricity hourly markets, which are well known for being peculiarly organized markets in which agents behavior is set in advance (specifically in the day-ahead market), in any time before the previous day, can be (almost) freely revised before the previous day. But the most important feature of the day-ahead markets is that decisions are taken for the entire set of 24 hours. This complex decision process entails action taken by one agent specifically designed to profit maximization in the face of peak and off peak loads and other agents behavior.

Thus, it is clear that peak vs. off-peak fluctuations can be assumed, up to a point, to be exogenous or explainable by meteo-like variables, but strategic interaction within the 24 hour period cannot be ignored in treating data with standard filtering techniques. This explains why we have decided to work with the entire data set of hourly prices. In fact, we think that data smoothing in the attempt to cope with very high intra-day seasonality is not justifiable, because there is loss of relevant information. The relevance of specific hourly price variability is analyzed for instance by Wolak in the assessment of critical peak pricing (CPP) tariff experiments (Wolak, 2010).

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, the results from dynamic simulations based on forecast variance decomposition are discussed. Some final remarks follow in the concluding Section 5.

2. Some results on the European Electricity market convergence and integration.

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 the 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, expecially 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 the extreme events, find that in term of pair wise dependence between markets the dependence varies from almost independent to strongly dependent and that dependence is not symmetric. In particular German Market is regularly cospiking (upward movements) with all markets (French included) except the Scandinavian one and (ibidem, p. 12): " [it] has a large conditional probabilities of experiences downward movements when a neighbouring 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[4]. 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.

[4] 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).

3. The empirical strategy

The evidence presented in this section can be used to address the question of whether European electricity market have experienced convergence dynamics 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 smaple of *n* countries or markets. Thus, we use a multivariate specification for the four equation of electricity spot prices according to a Vector AutoRegressive (VAR) process of order p

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

Where $y_t' = [DE, AU, FR, IT]$. Equation (1) can be represented in its isomorphic Vector Error Correction (VEC) form:

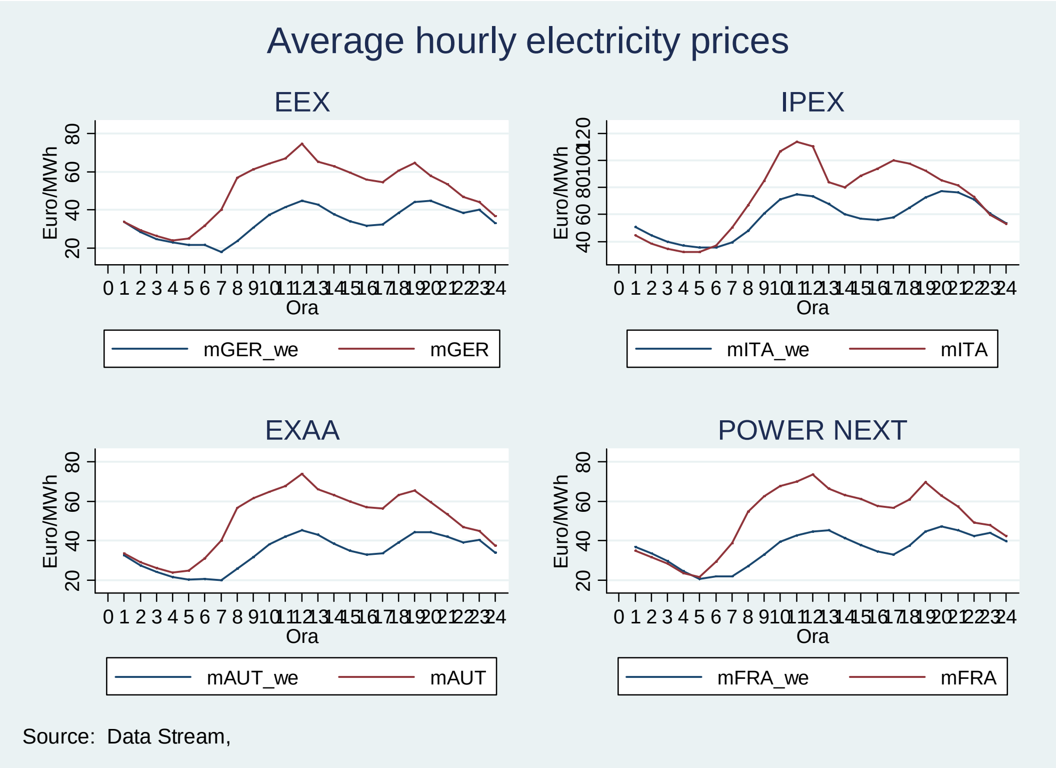
$$\Delta\mathbf{y}_t = \mathbf{\Pi}^y \cdot \mathbf{y}_{t-1} + \sum_{l=1}^{p-1} \mathbf{P}_l^y \cdot \Delta\mathbf{y}_{t-l} + \boldsymbol{\varepsilon}_t \quad , \quad \boldsymbol{\varepsilon}_t \sim N\left(\mathbf{0}, \mathbf{\Sigma}_\varepsilon\right) \tag{2}$$

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 $r < k = 4$ and can be decomposed as $\mathbf{\Pi}^q = \boldsymbol{\alpha} \cdot \boldsymbol{\beta}'$, where matrix $\boldsymbol{\alpha}$ contains the feedback coefficients (loadings) and matrix $\boldsymbol{\beta}$ the $r < 4$ 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 $4-r$ permanent shocks (the common trends). On the basis of the rank of matrix $\mathbf{\Pi}^y$, it is possible to identify different long-run equilibrium path for the electricity prices in the models. If all the elements of the 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 a long run representation of the integration process between markets.

4. Data and preliminary analysis

4.1. Data description and unit root analysis

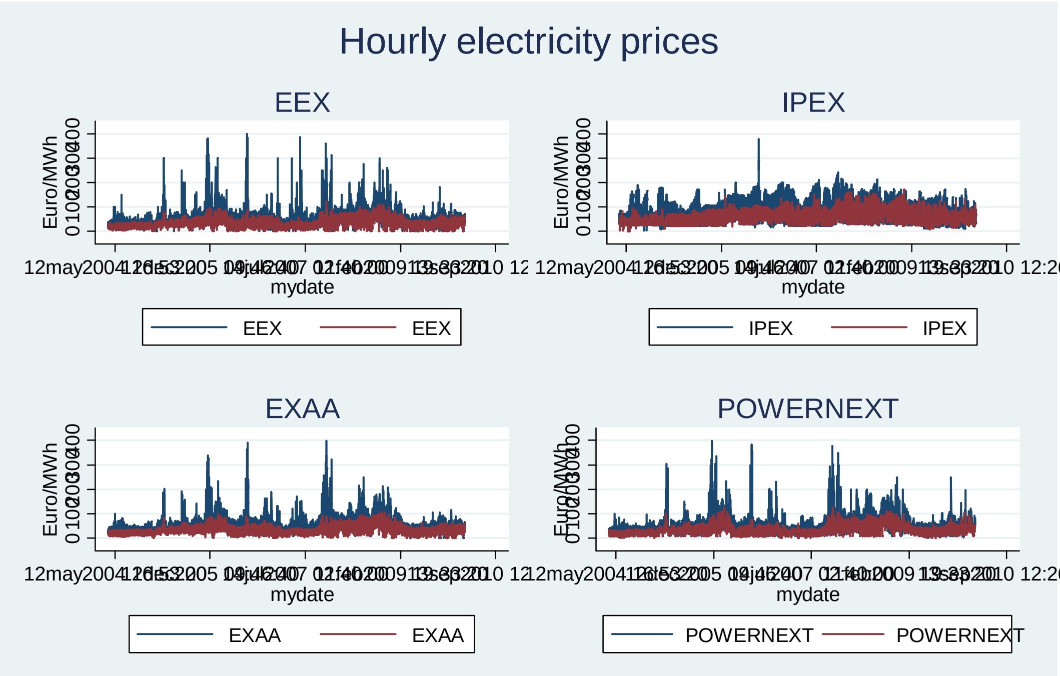
For the empirical analysis we employ hourly time series of electricity prices registered in four European wholesale markets: EXAA (Austria), EEX (Germany), Powernext (France) and IPEX (Italy). The hourly data for the electricity spot prices of the four European markets are derived from Data Stream. All prices are expressed in €/MWh. We compute the hourly daily price change as the difference in (the logs of) the spot prices registered in the same hour between two consecutive days. As well known the electricity cannot be stored, e.g. the inventories cannot be used to arbitrage prices across over time, so it has to be consumed when it is produced and consequently it shows characteristics more similar to a service than a good. The main empirical finding is that spot prices are characterized by volatility, extreme values and seasonality. Figure 1 shows the average hourly prices in four markets in week-ends and week days.



Prices show a clear bimodal distribution with two different hours in the day which are markedly higher than neighbouring values: these are hours between 11 and 12 a.m. and 6-8 p.m.. This type of distribution suggests that using a daily positional index it is impossible to fully take in account the real data generation process and, consequently, the policy implications of the econometric analysis could be biased, partial and limited.

In a comparative perspective across different European markets, data shows clearly that the Italian IPEX has values structurally higher if compared with the other markets. On average, Italian prices exceed others by 30-50% for each hour of the day.

Figure 2 shows the full distribution of hourly prices in the four markets. IPEX is characterized by a smaller range of price variation. Indeed in the other three markets we can see that prices have occasional spikes and go up over the threshold of the 500 Euro/MWh while this doesn't occur in Italy where the price are however constantly higher.



Red line week end and Blu line week day
Numbers of hour in which markets set prices grater than 400Euro/MWh: EEX = 20; EXAA = 23; POWERN. = 42
Source: Data Stream,

Finally table 1 shows the full descriptive statistics used in the econometric analysis.

Table 1 – 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*

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, we are unable to reject the unit root-null hypothesis at conventional nominal levels of significance and when we take the first difference we find evidence of stationarity in the series

Thus we find evidence that each of the electricity series has a unit root (or a stochastic trend) in its univariate time series representation. Te next step is to consider (under the the multivariate rapresentation of these series and test whether the stochastic trends are common to several of the series. That is, although each series contains a stochastic trend, in a vector process the stochastic trends may be shared (i.e. they may not be distinct). 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.

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.

Table 2 – Unit Root Tests

ADF tets	*DE*	*AT*	*FR*	*IT*
Deterministic part	C	c	c	C
Test statistics				
	ΔDE	*ΔAT*	*ΔFR*	*ΔIT*
Deterministic part	-	-	-	-
Test statistics				

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).

[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 KPSS, 1992) to check for robustness. The results are qualitatively similar (available from the authors upon request).

4.2. Model specification and cointegration tests

Estimating equation (2) requires taking two steps. First, 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. Second, 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 3, upper part) and multivariate (Table 3, lower part) diagnostic tests indicate that estimated residuals match the multi-normal distribution in a satisfactory way both at single equation and system level.

Table 3 – Misspecification tests

(a) Univariate misspecification tests

	DE	*AT*	*FR*	*IT*
$AR_{(1-7)}$	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]
$ARCH_{(1-7)}$	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

$AR_{(1-7)}$	1.1765 [0.1397]
Normality	13.024 [0.1110]
Heteroscedasticity	0.5572 [1.0000]

Note: p-values in square brackets

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 against the

[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 the time. The graph shows that the first three statistics grow in fact linearly as expected, while the fourth one is less clearly increasing (graphs for recursive trace test statistics are available from the authors upon request).

alternative suggests the results show that all variables are statistically different form zero [Panel (b)]. Further, none of variable is stationary by itself in the cointegration space, in a way consistent with the univariate unit root and stationarity tests [Panel (c)].

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 – 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.

4.3. Testing market integration in the long run

A key issue in the empirical investigation is establishing 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 conitegration space on the form:

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

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), calculated using the Bartlett small-sample correction (with estimated factor of 4.72), indicate that the restrictions are not rejected by the data at the usual significance levels (p-value of 0.115).

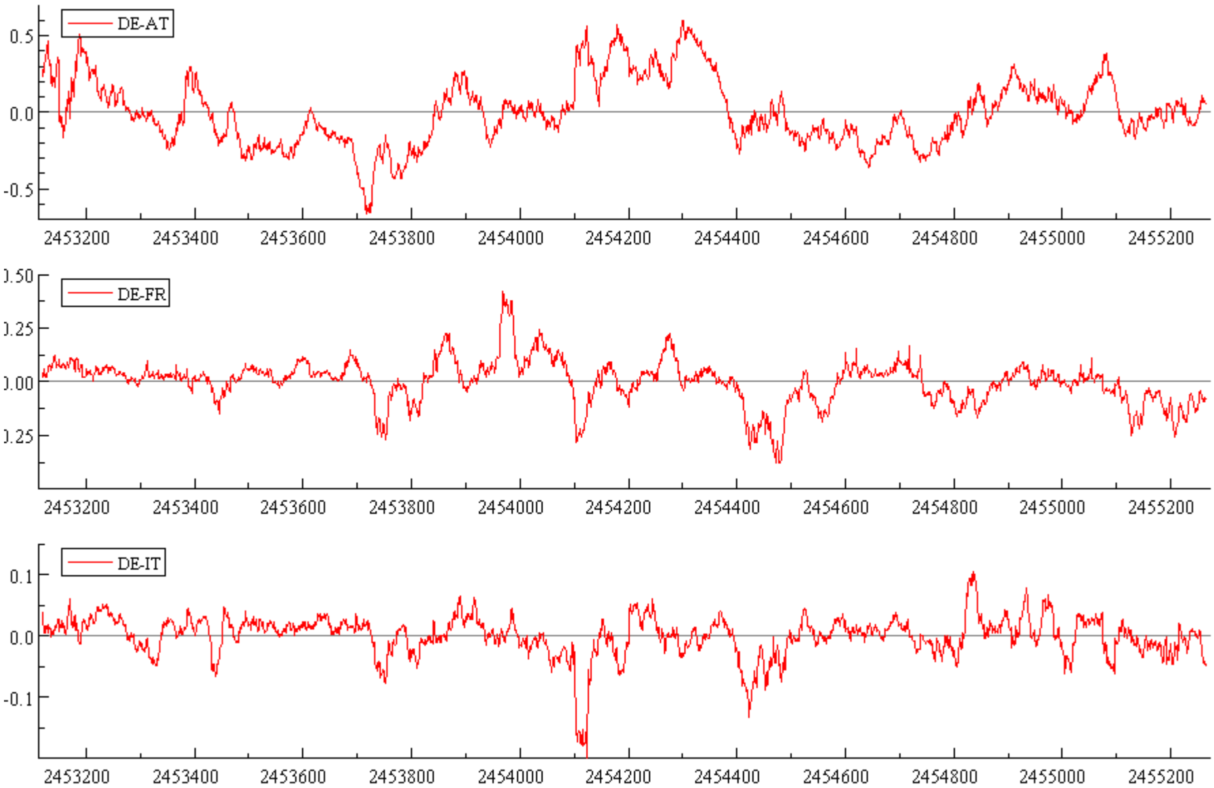
We also test for Granger-Causality in the whole system in order to verify if DE-prices "Granger-cause" the other variables in the model. Thus, we perform the usual F-test on the significance of lagged values of DE in the equations of AU, FR and IT. Under H_0: "DE" does not Granger-cause "AU, FR, IT". [Test statistic $_l$ = 1.6592; pval-F(l; 57, 8264) = 0.0014]. The test confirms that DE cause "AU, FR, IT". Finally, as robustness, we develop also a test for Instantaneous Causality. Under H_0 No instantaneous causality between "DE" and "AU, FR, IT" exist.

The result [Test statistic: c = 828.0805 pval-Chi(c; 3) = 0.0000] is consistent with the expectations. Figure 1 presents the cointegration relationships from the R-model.[7] There appears to be a clear cointegrating relationship in all three cases. Once the cointegration space is identified, the long-run properties of system (5) are analysed by looking at their persistence profiles (Pesaran and Shin, 1996), which make it possible 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.

[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 (see, Johanesen, 1995).

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.

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

In all cases, the convergence towards the steady-state follows a decreasing trajectory, with the adjustments from disequilibrium that come to an end within the fifth year of simulation. 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]

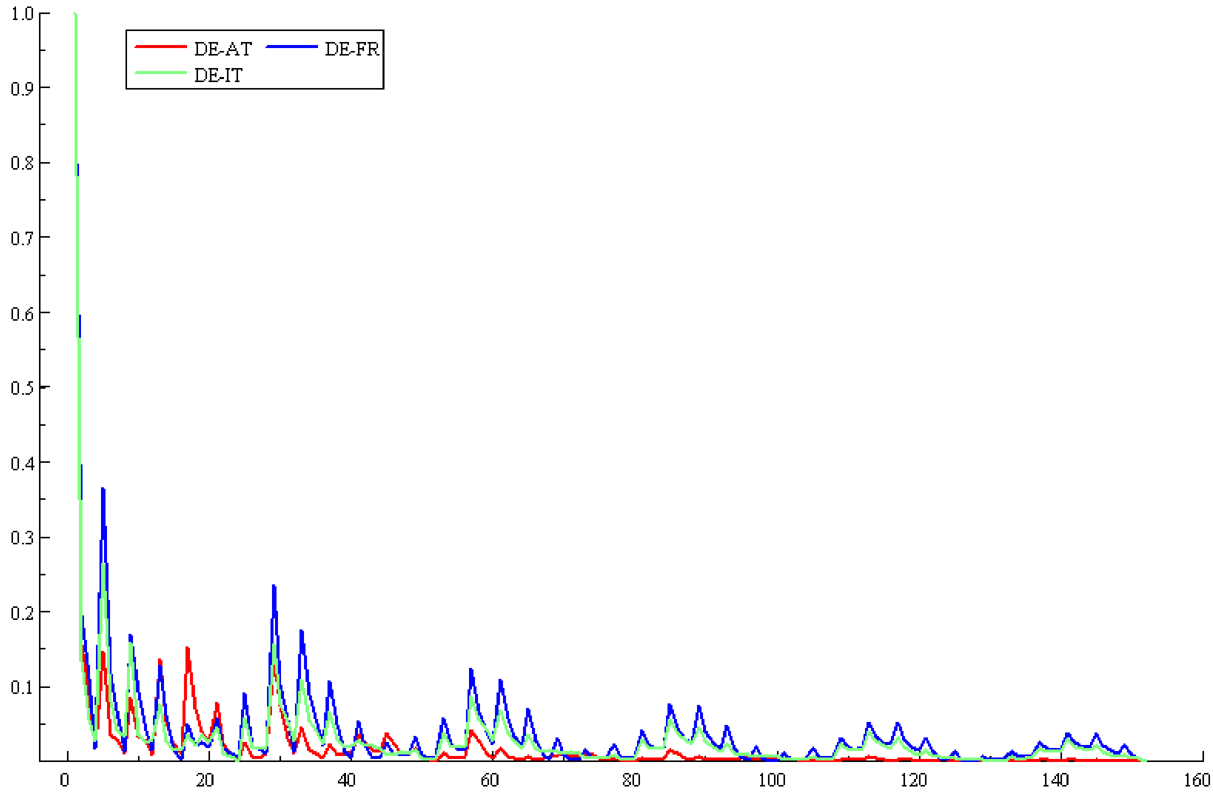
[8] The size of all the shocks analyzed in this section is set equal to one standard deviation.

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

4.4. Modelling the short-run: 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 threshold,[10] according to the Sequential Elimination of the Regressors Testing Procedure (SER/TP) proposed by Brüggemann and Lütkepohl (2001).

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.

Specifically, the statistically significant parameters of α matrix give useful information about how national market models move around the long-run equilibrium path. Table 5 reports the coefficients estimated by 3SLS only for the α matrix[11]. The analysis of the elements of the loading coefficients matrix allows to highlight some interesting results. The

[10] 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.

[11] The other coefficients are not reported for save space, but are available under request.

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 the speed of adjustment towards equilibrium is higher for Austria. Finally, there is evidence of some influence of $\varepsilon_1, \varepsilon_2$ and ε_3 on the other market equations.

Table 5 – VECM model estimated by 3SLS- The long run

	ΔDE	*ΔAT*		*ΔFR*		*ΔIT*	
$\varepsilon_{1,t-1}$	.	-	(0.035)	-	(0.043)	.	
$\varepsilon_{2,t-1}$	.	0.122	(0.018)	-	(0.021)	-	(0.020)
$\varepsilon_{3,t-1}$	.	-	(0.013)	-	(0.006)	-	(0.019)

Notes. Standard errors in round brackets.

Overall, this means that even if we are able to identify bilateral equilibrium conditions *versus* the German electricity markets, our model allows also for spillover effects between markets. Therefore, even if in our model the integration process is driven by the dynamics of the German system there are also other interesting relationships between other counties which characterized the process of convergence in European electricity markets.

5. 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 idiosyncratic shocks hitting the European electricity markets considered.

The model reduction process has two further implications. Firstly, dynamic simulations may differ, even markedly, from those derived from an unrestricted model. Secondly, dropping statistically coefficients can improve the quality of the forecasts generated by the model (Clements and Hendry, 2001, p. 119). Here we focus on the former issue, while the latter is discussed in the following Section.

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 $k^2 = 16$ 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 $r(k-r)=3$ additional restrictions and allows to distinguish transitory shocks (three in our case) from permanent (one) innovations. The remaining 3 restrictions are obtained by imposing a recursive scheme in the matrix of the transitory shocks in which the causal order of the variables is chosen following the size of the adjustment coefficients estimated previously. Thus, the causal order is the following: Austria, France and Italy. The permanent shock is derived from the permanent component of the system (that is, the common trend) and represents the global-external shocks that hit 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 real exchange rate fluctuations.

Table 6 shows the percentage of the variance of each variable of the system explained by global, regional and idiosyncratic shocks, where the latter are expressed as percentage of regional impulses. The last column (mean) presents the average contribution of the shocks over the entire simulation span (60 months).

Table 6 – Forecast error variance decompositions

	ΔAT	*ΔFR*	*ΔIT*	Mean
Global shock	79.91	78.03	71.40	76.45
Regional shock	20.01	21.48	28.39	23.29
Idiosyncratic shock	*(12%)*	*(85%)*	*(50%)*	

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. Idiosyncratic shocks are then aggregated so as to quantify the overall relevance of regional factors in explaining spot prices fluctuations. The figures represent the percentage of the variance of each variable of the system explained by global, regional and idiosyncratic shocks, where the latter (in italics) are expressed as a percentage of regional disturbances. The last column (mean) presents the average contribution of the shocks over the entire simulation period (5 months).

As can be seen, the disturbance from the German market (the global shock), which represents the symmetric shock hitting the other country markets as a signal of price formation, is the main driving force of electricity movements.

6. Conclusions

In this paper we have estimated a model to test integration and convergence among four European electricity markets. The main empirical evidences are the 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).

FEVD analysis shows that IT 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 is typically the fuel price shock) indicates that there are other factors, like non competitive strategic behavior, influencing equlibrium prices, which motivates future research

References

Balanguer, J. (2011). "Cross-border integration in the European electricity market. Evidence from the pricing behaviour of Norvegian and Swiss exporters," *Energy Policy,* 39: 4703-4712.

Bernard, A. B. (1991). “Empirical Implications of the Convergence Hypothesis," CEPR Publication 239, Center for Economic Policy Research, Stanford University, January.

Bosco, B., L. Parisio, M.M. Pelagatti and F. Baldi (2010). "Long-run Relations in European Electricity Prices," *Journal of Applied Econometrics*, 25: 805-832.

Brüggemann, R. and H. Lütkepohl (2001). “Lag Selection in Subset VAR Models with an Application to a U.S. Monetary System," In R. Friedmann, L. Knüppel and H. Lütkepohl (Eds.) Econometric Studies: A Festschrift in Honour of Joachim Frohn. Münster: LIT Verlag: 107 - 128.

Bunn, D.W. and A. Gianfreda (2010). “Integration and Shock Transmission Across European Electricity Forward Markets,” *Energy Economics,* 32: 278-291.

Cartea, Á. and C. González-Pedraz (2012). “How Much Should We Pay for Interconnecting Electricity Markets? A real options approach,” *Energy Economics,* 34: 14-30.

Clements M.C. and D.F. Hendry (2001). *Forecasting Non-Stationary Economic Time Series,* MIT Press, London.

Cornwall, N. (2008). “Achieving Electricity Market Integration in Europe”. in F.P. Sioshansi (Ed.), *Competitive Electricity Market –Design, Implementation, Performance-*. Oxford: Elsevier. 95-138.

Dickey D.A. and W.A: Fuller (1979). “Distribution of the Estimators for Autoregressive Time Series with a Unit Root,” *Journal of the American Statistical Association,* 74: 427-431.

Engle, R.F. and C.W.J. Granger (1989). “Co-integration and Error Correction: Representation, Estimation, and Testing,” *Econometrica,* 55: 251-276.

Erdogdu, E. (2010). “Electricity Market Reform: Lessons for Developping Countries”, Cambridge Judge Business School, -PHD FIRST YEAR REPORT 2009-2010- Retrrivied from: http://mpra.ub.uni-muenchen.de/27317/1/MPRA_paper_27317.pdf [13-4-2011].

European Commission (2006). “COM(2006)841 final -Communication from the Commission to the Council and the European Parliament- Prospects for the Internal Gas and Electricity Market,” Retrivied from: http://ec.europa.eu/energy/electricity /package_2006/index_en.htm [15-3-2011].

European Commission (2007). “Third Energy Package of the European Commission,” Retrivied from: **Errore. Riferimento a collegamento ipertestuale non valido.**index_en.htm [10-1-2011].

Glachant, J.M. and F. Levêque (2009). “The Electricity Internal Market in the European Union: What to do Next?”. In J.M. Glachant and F. Levêque (Eds.), *Electricity Reform in Europe: Towards a Single Energy Market.* Cheltenham: Edward Elgar. 3-33.

Green, R. (2007). “EU Regulation and Competition Policy among the Energy Utilities,”, IESE -Conference on the 50th anniversary of the Treaty of Rome-. Retrivied from: ftp://ftp.bham.ac.uk/pub/RePEc/pdf/08-01.pdf [22-8-2010]

Johansen, S. (1995). “Likelihood-Based Inference in Cointegrated Vector Autoregressive Models,” Oxford: Oxford University Press.

Kwiatkowski, D., P.C.B. Phillips, P. Schmidt and Y. Shin (1992). “Testing the Null 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: 159-178.

Lindström, E. and F. Regland (2012). “Modelling extreme dependence between European electricity markets,” *Energy Economics, doi: 10.1016/j.eneco.2012.04.006.*

Lu, Z., Z. Dong and P. Sanderson (2005). “The Efficient Market Hypothesis and Electricity Market Efficiency Test,” IEEE -Transmission and Distribution Conference and Exhibition: Asia and Pacific, IEEE/PES-: 1-7.

MacKinnon J.G. (1996). “Numerical Distribution Functions for Unit Root and Cointegration Tests,” *Journal of Applied Econometrics*, 11: 601-618.

Pelagatti, M.M., B. Bosco, L. Parisio and F. Baldi (2007). “A Robust Multivariate Long Run Analysis of European Electricity Prices,” Fondazione Eni Enrico Mattei Working Papers n. 162Retrivied from: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1035901 [19-5-2010]

Pesaran, H.M. and Y. Shin (1996). “Cointegration and the Speed of Convergence to Equilibrium,” *Journal of Econometrics*, 71: 117-43.

Pesaran, H. M., Y. Shin and R.P. Smith (2000). “Structural Analysis of Vector Error Correction Models with Exogenous I(1) Variables,” *Journal of Econometrics*, 97: 293-343.

Phillips, P.C.B. and P. Perron (1988). “Testing for a Unit Root in Time Series Regression,” *Biometrika*, 75: 335–346.

Pollitt, M. (2009). “Evaluating the Evidence on Electricity Reform: Lesson for the South East Europe (SEE) Market,” *Utilities Policy*, 17: 13-23.

Thomas, S. (2003). “The Seven Brothers,” *Energy Policy*, 31: 393-403.

Thomas, S. (2007). “Corporate Concentration in the EU Energy Sector,” -Report commissioned by: European Federation of Public Service Unions-. Retrivied from: http://gala.gre.ac.uk/3139/1/PSIRU_9722_-_2007-03-E-Energyconcentration.pdf [12-4-2011]

Thomas, S. (2009). “Corporate Policies in the EU Energy Sector,” -Report commissioned by: European Federation of Public Service Unions-. Retrivied from: http://gala.gre.ac.uk/1746/1/2009-03-E-corppolicies.pdf [3-10-2012].

Trillas, F. (2010). “Electricity and Telecom Reforms in the EU: Insights from the Economics of Federalism”, IESE –Business School- University of Navarra WP-861.

Warne, A. (1993). “A Common Trends Model: Identification, Estimation and Inference,” IIES -Seminar Paper, Stockholm, Stockholm University, 555.

Wolak, F. (2010), “An Experimental Comparison of Critical Peak and Hourly Pricing: The Power Cents DC Program,” Stanford University. Retrivied from: http://sedc-coalition.eu/wp-content/uploads/2011/06/Wolak-10-03-15-PowerCentsDC-Paper.pdf [21-7-2011]-

Zachmann, G. (2008). “Electricity Wholesale Market Prices in Europe: Convergence?,” *Energy Economics*, 30: 1659 – 1671.