PRICE CONVERGENCE AND INTEGRATION IN THE GERMANY, FRANCE AND ITALY ELECTRICITY MARKETS

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ABSTRACT

This paper examines empirically the electricity market integration process for Germany, France and Italy countries by investigating possible price convergence. Two empirical approaches have been considered to investigate this issue : cointegration analysis and state space model with time varying coefficients during the period 06 July 2009 to 15 April 2011.

Using both methods, empirical results show that the Germany and France markets are highly integrated. For the Germany and Italy, and France and Italy pairs no price convergence has been detected when the cointegration analysis is employed and when using the time varying coefficients model, empiricl results show evidence for weak convergence.

Keywords

Electricity market integration, cointegration and time varying coefficient model.

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1. INTRODUCTION

In recent years, there is a growing interest on the creation of a single electricity market for the Europe countries. This objective has been one of the most important priority of the European Union's. As in others countries, until the 1980s the electricity market in Europeans countries were dominated by the vertically integrated publicly owned. Since this date, the argument of the natural monopoly of the electricity industry has begun to be questioned. Like other industries, the liberalization process in electricity sector seems to be necessary in order to make industry efficient as supported by Hunt (2002). In this context, many countries began to introduce reforms in electricity sector in order to make the markets integration. Indeed, integration of markets can be a solution of domination of monopoly electricity companies. Integration between markets is about changing existing monopoly companies by separating some functions and combining others, and sometimes creating new companies[1]. The electricity market liberalization constitutes a very important step for markets integration. To achieve this goal, several reforms have been introduced by the European Union's such as the (98/30/EC) and (2003/55/EC) directives and the recent 2009 energy package.

In theory, there are many reasons for Europeans electricity markets integration. Indeed, geographical proximity and dependence on networks infrastructure between European countries requires the formation of an electricity single market. Bergman (2003) states that the connection between geographical extent of the market and the degree of competition was one of the reasons for the early integration of the Norwegian and Swedish electricity markets. To allow trade-offs between markets, the concentration of a single market organized as in the four Nordic countries (Norway, Sweden, Finland and Denmark) need the harmonization of physical markets rules and the supporting regulatory and political conditions. However, as noted by Neuhoff et *al.* (2011) there will be a problem of an insufficient network capacity and the congestion problems that will result. So, inter-connector capacities sufficient between Europeans countries is seem to be an important condition for markets integration.

The majority of researchers agree that there are many benefits on the different degree of electricity markets integration process[2]. Zhu et *al.* (2004) state that regional electricity grid interconnections can generate a variety of benefits including environmental, social and economic gains. For Pierce et *al.* (2006), integration markets can reduce costs especially by reducing transaction costs, price volatility and mitigating market power by dominant players. Electricity market liberalization can introduce competition, attract investment, introduce customer choice, reduce debt and promote integration of the grid (Harris, 2007). Joskow (2008) indicated that electricity sector reforms have significant potential benefits but also carry the risk of significant potential costs if the reforms are implemented incompletely or incorrectly. In addition, increased economic efficiency privileged market concentration and higher security of supply (Creti et *al.*, 2010). Market organization

[1]See Hunt (2002).

[2] For more details of the benefits of the degree of electricity markets integration see pierce et al (2006) and Newbery et *al.* (2013).

affects performance, efficiency, and prices in competitive electricity markets (Mansur and White, 2012). Connecting infrastructure reduces the dependency of markets on a limited number of sources of supply and would facilitate the short and long term trading of energy, renewable, balancing services and therefore impulse demand (Newbery et *al.*, 2013).

In empirical literature, there are several studies that focuses on whether the EU reforms have been effective in delivering a single electricity market[3].There is obviously a close connection between price convergence and markets integration. Generally, in order to verify the degree of markets integration, it should be checked the prices movement. Bergman (2003) emphasize that from an economic point of view, a market is well integrated only if there is a single price of the product that is traded on the market in question. For Growitsch and Nepal (2011), the notion of market integration or separation can be analyzed respectively by testing for the convergence or divergence of the prices of the considered markets. In order to evaluate the success of wholesale market reforms in Germany, they employed Kalman filter analysis between the spot market prices at the power exchange and the OTC market.

Bower (2002) showed, using correlation and cointegration analysis, that some European electricity markets (Nordic countries, Germany, Spain, the UK, and the Netherlands) were already integrated to a certain extent by 2001. Armstrong and Galli (2005) by analyzing the France, Germany, the Netherlands and Spain electricity markets, conclude that European electricity price converged in the period 2002-2004. Zachman (2008) shows that 59% of the analyzed hourly pairs of national wholesale electricity price converged in the period 2002-2006 in Germany electricity market. Bosco et *al.* (2010) by multivariate long-run dynamic analysis, showed that there is a four highly integrated central European markets (France, Germany, the Netherlands and Austria). For short run interdependencies of the European electricity markets see Jbir and Charfeddine (2012). In contrast, Boisseleau (2004) that focused on regression and correlation analysis determined that the level of integration of European markets is quite low. Recently, Bollino et *al.* (2013) test integration dynamics within four European electricity markets (Austria, Germany, France and Italy) using multivariate cointegration techniques. Empirical results provide evidence that German market constitutes a common stochastic trend driving the long-run behavior of other markets. Their 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. Using the same methods employed in this paper, the cointegration analysis and the state space model with time varying coefficient, Growitsch et *al.* (2013) investigate price convergence of German natural gas markets. Their results suggest a fair price convergence between the corresponding markets zone.

This study aims to evaluate the degree of electricity markets integration in three Europeans countries (Germany, France and Italy) by checking for price convergence. Two empirical econometric approaches have been employed in this

[3]For more detail on European Electricity market convergence and integration studies see Bollino et *al.* (2013).

paper. Firstly, we used the cointegration analysis approach which test for the presence of a long-run relationship between each pair of the three electricity prices. This method is employed as a pre-test of market integration as it lies on the assumption that structural relation among prices is fixed over the period under study. Secondly, we employ the state space model with time varying coefficient to overcome the limits of the co-integration analysis. The state space model allows us to test for possible dynamics of price convergence over time considered as the result of price developments along with structural changes over time. The current study differs from the growing and already existing literature on testing for price convergence/electricity market integration in several ways. First, we study electricity price convergence of the three major European countries, Germany, France and Italy, not yet explored in the empirical literature by using a recent daily prices data covering the period 2009-2011. Second, we test for static (using cointegration analysis) and dynamic (state space model) price convergence which allows us to test for reforms and policies success. Moreover, it allows us to test for the hypothesis of evolving electricity market integration motivated by the European Commission projects. Third, we analyses the implications of the reforms and structural changes introduced in these three electricity markets.

The remainder of this paper is organized as follows. Section 2 presents electricity market in the three Europeans countries. Section 3, presents the data and empirical methodology. Section 4 discusses empirical results. Finally, section 5 conclude and presents policy implications of our empirical findings.

2. ELECTRICITY MARKET IN EUROPE

Like all countries, the electricity industry in Europe was under the monopoly control of government. The reforms in the European electricity industry have been introduced by the first and the second Electricity Directives of 1996 and 2003, respectively, and have more recently been enhanced by the 2009 energy package. With the European Charter of Energy, these directives give the order legal of reforms for electricity sectors of the UE.

Between 1991 and 2011, gross electricity generation in the EU-27 area increased from 2631 TWh to 3280 TWh which corresponds to a 25% increases, (Pellini, 2014). During this period, renewable generation increased by 18 times (20 TWh to 364 TWh), and natural gas grew by 3.7 times, going from 188 TWh to 693 TWh. Germany was the largest producer in the EU-27 area, with 609 TWh of electricity generated, France accounted for 562 TWh and finally with 303 TWh for Italy. Germany and France was the main net exporting Member State. However, Italy ranked first among the net Europeans importers of electricity with 45,732 GWh of net import. In EU, the industry sector remained the largest consumer of electricity with 37% in 2011. While the share of electricity consumed by the weight of the services sector and households are equal with 29 %.

In the EU, the infrastructure of electricity networks formed by transmission grids and distribution grids is essentially a public ownership, except Germany and Italy. According to the European Commission (2012), in 2010, Germany has 100%, Italy 70% and France 15.5% Private Ownership of electricity networks. In 2011, the annual average traded volumes as a percentage of consumption are respectively 13 for France (EPEXSPOT), 41for Germany (EPEXSPOT) and 58 for Italy (IPEX).

Another important issue when examining price convergence is the process of price formation. In theory, the equilibrium price is the result of confrontation between demand and supply. In electricity markets, equilibrium price is also influenced by the different and complex strategies of electricity generators such as common regulatory norms across Europe, differences in interconnections capacities, generation technologies and costs. For the three markets considered in this paper, we notice a significant difference in their technologies used for generating electricity production. Table 1 presents the production of electricity for the Germany, France and Italy countries in 2000 and 2011. In parenthesis, we report the share in percentage of each technology employed in the total production. For the Germany, we remark that on average 60% of the total electricity production is generated by the traditional thermic energy such as Lignite, coal, oil and gas. In addition, we remark that the fall of the share of electricity production generated by nuclear which decrease from 29.41% in 2000 to 17.61% in 2011 is compensated by an increase of renewable energy sources[4]which progressed from 6.57% in 2000 to 20.19% in 2011. The others energy resources remain fixed to about 4% from total production.

TABLE 1: ELECTRICITY PRODUCTION ACCORDING TO TECHNOLOGY EMPLOYED

	Germany Production		France production		Italy production	
	2000	2011	2000	2011	2000	2011
Traditional Thermic Energy	346.6 (60.11%)	355.8 (58.02%)	53 (9.81%)	53.8 (9.56%)	220.5 (79.72%)	228.5 (75.51%)
Nuclear energy	169.6 (29.41%)	108 (17.61%)	415 (76.85%)	442.4 (78.60%)	0 (0%)	0 (0%)
Renewable energy sources	37.9 (6.57%)	123.8 (20.19%)	69.9 (12.94%)	64.35 (11.43%)	42.4 (15.3%)	57 (18.83%)
Other energy sources	22.6 (3.92%)	25.6 (4.17%)	2.1 (0.40%)	2.25 (0.40%)	13.7 (4.95%)	17.1 (5.65%)
Total production	576.6	613.2	540	562.8	276.6	302.6

Source: the data are collected from the website of the national electricity companies.[5]

For France, the electricity production is mainly by nuclear energy where the share of electricity production generated by nuclear remains approximately constant, about 76.85% in 2000 and 78.60% in 2011. Traditional thermic energy account for about 9.81% in 2000 and 9.56% in 2011. The share of renewable energy sources are

4Electricity production generated Renewable energy resources (RER) for Germany include hydro, wind, biomass and photovoltaic. For France and Italy, it includes hydro, wind and photovoltaic.

5www.destatis.de and www.bmwi.de web sites for Germany, the www.developpement-durable.gouv.fr for France and www.terina.it for Italy respectively.

approximately equal to 13% and the others energy sources contribute to 0.40%. Finally, like the Germany structure of electricity production we remark that the Italy electricity production is dominated by the traditional thermic energy which account approximately for 79.72% in 2000 and 75.51% in 2011. Renewable energy sources account for 15.3% in 2000 and 18.83% in 2011 and finally the other energy sources account approximately for 5% in 2000 and 2011.

3. EMPIRICAL METHODOLOGY

In the last years, France, Germany and Italy have introduced many reforms[6] in their electricity markets in the attempt to create a single European market for electricity. To investigate the potential integration in the wholesale electricity prices of these three European markets, we propose to use twoempirical approaches: the cointegration technique and the time-varying state space approach. The use of these two kind of techniques is mainly motivated by their complementarity. In fact, the cointegration analysis allows to test whether the electricity prices tend towards a common long-run equilibrium price[7] which is considered as first indication for markets integration[8].In the other hand, the time-varying coefficient (state space) model is employed to examine price convergence over time. While the first method is a static form of testing price convergence, the second approach is a time varying dynamic approach. These two approaches are presented in the following two subsections 3.1. and 3.2.

3.1 The cointegration and VECM approach

In empirical studies, one of the most important econometric tools used to examine whether the European electricity market have experienced convergence in the last years is the cointegration approach. For this purpose, we use Bernard and Durlauf (1995, 1996) definition of convergence which consider that there are convergence between several countries if the long-term forecasts of prices differences tend to zero as the forecasting horizon tends to infinity. Inthe econometric point of view, this definition can be examined, for the bivariate case, by testing if prices for countries *i* and *j* are cointegrated with cointegrating vector [1, -1]. For the multivariate case, a necessary condition for markets convergences is that there be *n-1*cointegrating vectors for a sample of n countries.

To start with this method, consider a vector Y_t of $k-I(1)$ time series that follow a vector autoregressive model VAR(p) given by,

$$Y_t = A_0 + A_1 Y_{t-1} + A_2 Y_{t-2} + ... + A_p Y_{t-p} + u_t \quad \textbf{(1)}$$

[6]The three directives that organize the European electricity industry and a series of recommendations such as new market designs, common regulation of cross border trade, and son on, see for instance Zachmann (2008), Bosco et al. (2010), and Growitsch and Nepal (2011).

[7]In this paper, we test for pairwise and mutivariate convergence of electricity prices.

Where Y_t is the vector of endogenous variables (FRA, GER, ITA). A_0 is a vector of intercepts. $A_1,\dots,A_n$ are a $(k \times k)$ matrix of parameters to be estimated. p is the order-lag chosen using the AIC and Shwartz criteria. Equation (2) can be rewritten in the vector error correction model (VECM) representation,

$$\Delta Y_t = A_0 + \Pi Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i Y_{t-i} + u_t \tag{2}$$

Where $\Gamma_i = -\left(A_{i+1} + \dots + A_p\right)$, for $i = 1,\dots, p-1$, and $\Pi = \left(A_1 + \dots + A_p - I_k\right)$. u_t is the residual of regression (3) that is supposed to be a white noise. The matrix Π in equation (3) is of particular interest as it represents the long-run relationship between electricity prices series. This matrix can be decomposed in the following form $\Pi = \alpha\,\beta'$. Where α represents the speed of adjustment to disequilibrium and β' is the matrix of long-run coefficients such that $\beta' Y_{t-1}$ represents up to $(k-1)$ stationary cointegrating relationships, which ensure that Y_t converges to their long-run steady state solution.

To test for cointegration between variables, we employ the trace statistic tests of Johansen (1988) and the maximum eigenvalue statistic tests of Osterwald-Lenum (1992). Precisely, we test whether the matrix Π has a reduced rank $r \le (k-1)$, indicating that there are r stationary cointegrating relationships between non-stationary variables in $VAR(p)$ model. To determine the rank r of the matrix Π, we use the following two tests, the trace test and maximum eigenvalue statistics.

The *trace statistic* tests the null hypothesis that the number of cointegrating vectors is less than or equal to *r* against a general alternative.

$$\lambda_{trace} = -T \sum_{i=r+1}^{k} \log(1 - \hat{\lambda}_i) \tag{3}$$

The maximum eigenvalue statistic tests the null hypothesis of r cointegrating vectors against the specific alternative of $r+1$,

$$\lambda_{\max}(r, r+1) = -T \log(1 - \hat{\lambda}_{r+1}) \tag{4}$$

Critical values of these two tests are respectively tabulated by Johansan and Juselius (1990) and Osterwald-Lenum (1992). The empirical results of these two tests will be analyzed in the next section. Note that the cointegration results are only used as a kind of pre-test whether markets are integrated or not. The closer β is to one, the better integrated the markets are see for instance following the line of argument of Barrett (1996), Baulch (1997a, 1997b), Barrett and Li (2002) Growitsch et al. (2010). As mentioned by many researchers, the cointegration analysis assumes a fixed relationship between prices over time, see for instance King and Cuc (1996) and Kleit (2001). This assumption has been widely criticized as it ignores the dynamics of possible convergence or divergence between these markets. To cope with this limit, we propose in following subsection a time-varying approach based on the state space model to analyze the price convergence dynamic of price over time.

3.2 The state space model

As noted in the previous section, the cointegration approach has been widely used to investigate electricity price convergence. However, considering that the structural relation among the electricity prices is fixed over the considered time period is not universally accepted in the empirical literature, see for instance Zachmann (2008), and Growitsch and Nepal (2011). In fact, the reforms and structural changes introduced in these countries have led to prices development over time which motivate to examine possible dynamic hypothesis of electricity prices rather than considering fixed relationship over time. Therefore, we introduce a time-varying coefficient into the linear relationship of prices to analyze the path of price convergence or divergence. This analysis can explain the dynamics of parallel price evolution for electricity markets. To analyze the strength of the pricing relationship, we consider a system with two equations (5) and (6).

Equation (5) below is the main equation which represents the linear relationship between electricity prices.

$$p_{i,t} = \alpha_{ij} + \beta_t . p_{j,t} + \varepsilon_t \qquad \textbf{(5)}$$

Where $\varepsilon_t \to N(0,\sigma_\varepsilon^2)$ and β_t is a vector of unobservable coefficients at time t which measures the strength of price convergence across countries. If $\beta_t = 0$, we can conclude that there is no relationship between the pairwise electricity prices and no convergence between electricity markets. In contrast, if $\beta_t = 1$, so there is a perfect convergence between markets.

Equation (6) is the transition equation which is given by,

$$\beta_t = \beta_{t-1} + \upsilon_t \qquad \textbf{(6)}$$

and $\upsilon_t \to N(0,\sigma_\upsilon^2)$ are white noise processes. By combining these two equations, we obtain the state space form of our approach. Estimation of the state space model (equations (5) and (6) is done by a recursive procedure of the Kalman filter, see for instance Kalman (1960).

4. EMPIRICAL RESULTS

4.1 Data set

We use a spot daily data of electricity prices of the three major European electricity markets: France, Germany and Italy. The data set is extracted from Datastream data base and covers the period from 06 July 2009 to 15 April 2011 (T=648 observations).We note that we have transformed prices to their logarithmic form[9] denoted as LGER, LFRA and LITA time series. Trajectories of the three prices series are presented in Figure 1.

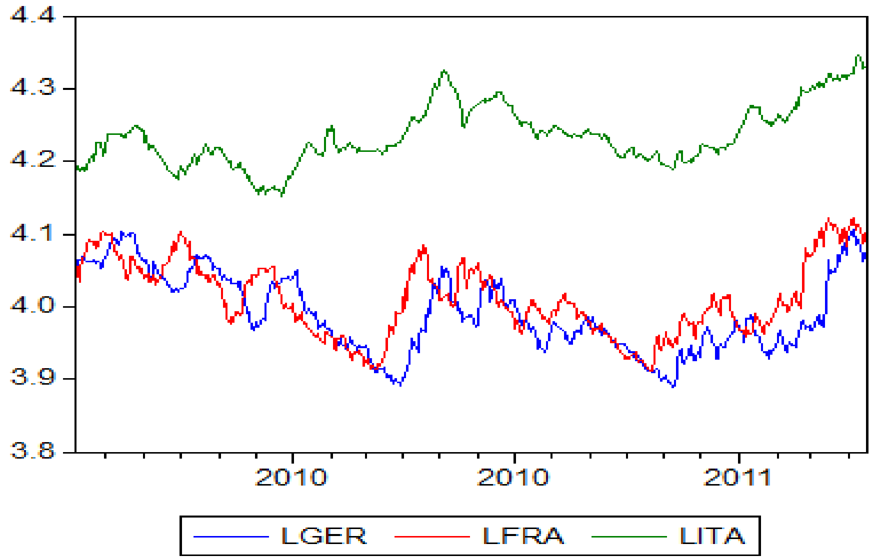

FIGURE 1: TRAJECTORIES OF THE LOGARITHMIC TRANSFORMED ELECTRICITY PRICES FOR FRANCE, GERMANY AND ITALY MARKETS (€/MWH)

Figure 1 shows that the three prices series have a common trend and share a same behaviour of price movement. This similar pattern is more pronounced for the Germany and French prices series. We remark also, that Italy electricity prices are all time higher than the Germany and France prices.

4.2 Preliminary analysis

A preliminary analysis of the statistical properties of the data is a necessary step before examining price convergence. We start by presenting descriptive statistics of the logarithm of prices, and the returns series. Then, we analyze the correlation between the European markets prices taken in pairs to determine the strength of the degree of interdependence and co-relation between prices. Finally, we test for the presence of unit root in the price level and first difference using the PP, ERS and KPSS unit tests[10] to determine the degree of integration of the prices series as the co-integration approach needs that all prices series are integrated with same order.

[9]We have also calculated the first difference of price electricity (the return series) r_t which is obtained by the following transformation, $r_t = 100*\left(\log\left(P_{it}\right) - \log\left(P_{it-1}\right)\right)$, where $\left(P_{it}\right)$ is the electricity price at day t for country i where $i = \{FRA, GER, ITA\}$.

[10]In this paper we use three unit roots tests statistics : the Phillips and Perron (PP) (1988), the Point Optimal Elliot-Rothenberg-Stock (ERS) (1996) and the Kwiatkowski, Phillips, Schmidt and Shin (KPSS) (1992) tests.

4.2.1 Descriptive statistics and correlation[11]

Table 2 reports the descriptive analysis of prices and returns of electricity series. It shows that the prices series (logarithm of price) are platykurtic with a positive skweness. The Jarque-Bera statistic shows that all prices electricity series are clearly not normally distributed. We conclude that the mean and standard deviation are approximately similar for both the French and Germany prices electricity series. The electricity prices means are equal to 54.180, 55.264 and 69.118 respectively for Germany, France and Italy and the standard deviation is approximately the same for all prices series. It is equals to 2.940, 2.876 and 2.839 for the Germany, French and Italy electricity price series respectively.

TABLE 2: DESCRIPTIVE STATISTICS OF THE LOGARITHM PRICES SERIES.

	Electricity's pricesseries					
	Mean	Std.dev	Sk.	Kur.	J-B	*p-value* of J-B
Germany	54.180	2.940	0.329	2.090	34.119	0.000
France	55.264	2.876	0.269	2.171	26.418	0.000
Italy	69.118	2.839	0.616	2.891	41.342	0.000

The normality test is the Jarque-Bera test which has a $\chi^2(q)$ distribution with q =2 degrees of freedom under the null hypothesis of normally distributed errors ,the critical value at the 5% level is equal to 5.99.

Table 3 reports the empirical results of the correlation coefficients between the three countries[12] taken in pair. This Table shows that all coefficients are significantly different from zero, especially for the Germany-France pairwise. This strong correlation can be viewed as a first indicator of markets integration[13]between Germany and France. In the other hand, correlations between Germany-Italy and France-Italy are also significantly different from zero.

[11]The simple (or linear) correlation analysis is the most widely used measure of market interdependence. It is also well-suited as a starting point for estimating the level of market integration. Indeed, the correlation coefficient between two time series price data can be used to determine whether these two markets are integrated (Stigler and Sherwin, 1985).

[12]The correlation between each pair of electricity prices allows us to determine the level of interdependence between all markets taken in pair.

[13]For electricity markets, the classical weaknesses of correlation analysis are avoided. For instance, one drawback of correlation analysis is that a misleadingly-low correlation coefficient can arise because one price series responds to another with a significant lag. Since electricity is non-storable such a lag problem cannot occur in electricity markets, e.g. a price spike on one market at 12.00 due to unusual weather conditions is unlikely to affect prices on another market later on. A misleading high correlation can occur if the prices in two locations are subject to a common influence. This is the case in electricity markets because day ahead price and week seasonality are important.

TABLE 3: CORRELATION COEFFICIENTS OF ELECTRICITY'S PRICES SERIES

	Germany	France	Italy
Germany	1	-	-
France	0.707 (0.079)	1	-
Italy	0.178 (0.079)	0.313 (0.079)	1

Standard deviations are in parenthesis (.)

Moreover, it is important to note that the fact that correlation coefficients are significantly different from 0 does not mean that there is price convergence. For instance, the higher value of correlation is associated to the presence of higher links. So, following table 3, we conclude that there is a strong links between Germany and France electricity markets. For the other pairs, the degree of links is weaker. We note also that the relation between France and Italy prices is more pronounced than that between Germany and Italy.

4.2.2 Unit root tests

A precondition for cointegration analysis is that prices electricity time series are integrated with same order. To test for the presence of unit root and for the degree of integration of prices time series, we use Philips Perron (PP), Elliot Rothenberg Stock Point Optimal (ERS P.O), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. Table 4 below reports the empirical results of these three tests. For the three series, the unit root tests clearly reject the hypothesis of the presence of unit root cannot be rejected of prices series. Moreover, Table 4 shows that the hypothesis of non-stationarity is be rejected for the first difference time series. Then, we can conclude that electricity prices series are integrated with order 1, I(1). This result is of great importance as it allows us to test for possible long-run relationship using the cointegration analysis. This latter topic will be examined in subsection 4.3 below.

TABLE 4: RESULTS OF THE PP, ERS P.O AND KPSS TESTS

	Level			First difference		
	PP	ERS	KPSS	PP	ERS	KPSS
Germany	0.045 (9)	8.223 (10)	1.002 (21)	-20.854 (8)	0.105 (8)	0.212 (9)
France	0.184 (7)	5.749 (8)	0.447 (21)	-22.366 (6)	0.137 (6)	0.188 (7)
Italy	0.857 (10)	10.635 (10)	0.995 (21)	-19.372 (7)	0.273 (7)	0126 (10)

Critical values for the PP, ERS (P.O) and KPSS tests at the 5% level of significance are -2.862, 3.260 and 0.463 respectively for the 5% level. In parenthesis (.) are the Newey-West Bandwith for the PP test, the lag length using the Schwartz criteria and the Newey West Bandwith.

4.3 Cointegration and Vector Error Correction model (VECM)

As all three electricity prices are integrated with order one, I(1), one can test for the presence of long-term relationship using cointegration approach developed by Johansen (1989, 1991). We start by examining the bivariate case, then we test for multivariate case. Note also that when the hypothesis of cointegration is accepted, a long-term relationship between the I(1)variables can be captured by equilibrium error correction model (VECM). The presence and/or rejection of a cointegration relationship have strong implications on markets integration and price convergence.

Empirical results of the λ_{trace} and $\lambda_{\max}$ tests for the 3 pairs of prices,Germany-France, Germany-Italy and France-Italy, are reported in Table 5 and summarized in Table 6. Empirical results show that only the Germany and Franceprices has a cointegrating term indicating the existence of a long term relationship between these two variables. This result means that the Germany and French electricity price time series share a common stochastic trend which is viewed as a consequence of the recent reforms introduced in these two electricity markets.

TABLE 5: RESULTS OF BIVARIATE COINTEGRATION TESTS

	Germany-France		Germany-Italy		France-Italy	
	λ_{trace}	$\lambda_{\max}(r,r+1)$	λ_{trace}	$\lambda_{\max}(r,r+1)$	λ_{trace}	$\lambda_{\max}(r,r+1)$
$r=0$	46.352	41.249	6.680	6.376	5.424	4.317
$r=1$	5.103	5.103	0.304	0.304	1.107	1.107

Critical values for the trace test are equal to 29.68 and 15.41 for r=0 and r=1 respectively.
Critical values for max-eigenvalue test are 20.97 and 14.07 for r=0 and r=1, respectively.

The empirical results concerning electricity price convergence of the pair Germany-France is as expected for several reasons. First, the highly correlation coefficient between LGER and LFRA indicates the existence of high level links between these two markets. Second, reforms and common features shared by these two countries make that electricity prices of these two countries have a common trend. In empirical literature, this finding confirms empirical results obtained by Zachman (2008). For the two others pairwise, the Germany-Italy and France-Italy, the hypothesis of cointegration is highly rejected. There is no electricity price convergence between the two pairs.

TABLE 6: BIVARIATE COINTEGRATION RESULTS

	Germany	France	Italy
Germany	-	-	-
France	Yes	-	-
Italy	No	No	-

Yes : existence of long-run relationship
No: Not existence of long-run relationship

Estimation results of the long-term relationship between LGER and LFRA variables are reported in Table 7. The equilibrium vector error correction model (VECM) given in equation 2 is defined by two parts. A long term part which models the long-run relationship between LGER and LFRA and a short-term relationship which reports the short-run dynamics between all electricity prices transformed in difference. The empirical results of this long-term relationship between LGER and LFRA are reported in lines 3 and 4 of Table 7. Line 3 reports the estimated values of the α vector and line 4 the estimated values of the β vector. The results show that only the α coefficient of the $\Delta LGER_t$ equation is significantly different from 0 and have a negative sign, suggesting the presence of return toward the long-run equilibrium. The estimated value of α is equal to -0.0389 which indicates that the LGER- LFRA pair takes approximately 25 trading days[14] to bring prices back to equilibrium. A period of 25 days is considered very long period and indicates that these two markets does not have a strong interconnection. The second part of the VEC model define the short-term dynamics between the electricity prices which is given by the estimated coefficients associated to $\Delta LGER_{t-1}$ and $\Delta LFRA_{t-1}$ in eq. 2. The estimated coefficients for the short-run dynamics are all significant except the coefficient for the $\Delta LFRA_{t-1}$ associated to the $\Delta LGER_t$ equation. This results indicates that the Germany electricity market is influenced only by itself positively, in contrast the French electricity market is influenced by itself positively and negatively by the Germany market.

In addition to the standard VEC model, we test in Table 7 two important restrictions. First, we test that $\beta = \left[1, -1\right]$. This restriction is of first importance when testing price convergence, the fact testing this restriction means that we test that changes in one electricity market is followed by the same change in the other market. For instance, a 1% price change in the Germany electricity market will be accompanied by an 1% change in the French markets electricity market. Empirical results reported in the last line of Table 6 show that the $\beta = \left[1, -1\right]$ restriction cannot be rejected. This means that there is strong electricity markets integration between the Germany and France markets. Second, we test also for the restriction that α is null in each long-run equation. Empirical results show that only for the second equation (the $\Delta LFRA_t$ equation) that this restriction is accepted.

For further investigation of long term relationships, in a next step we examine the hypothesis of price convergence between the three electricity markets by examining the hypothesis of multivariate long-run relationship between the three electricity prices using Johansen (1989, 1991) cointegration approach. For this end, we introduce the Italy price (LITA) in the bivariate previous analysis. Our methodology consists in two steps. First, we test for the presence of multivariate relationship using the λ_{trace} and $\lambda_{\max}$ tests statistics and when the hypothesis of long-run relationship have been accepted, we estimate the corresponding VEC model. In

[14]The α variable measures the speed of adjustment and the period needed to bring prices back to equilibrium is equal to $1/\alpha$ trading days.

a second step, we test the restriction that the Italy electricity market is not determinant in the long-run relationship between LGER and LFRA. To do that, we use the log-likelihood ratio (LR) test. All empirical results are reported in Tables 8 and 9 below.

TABLE 7: ESTIMATION OF THE VECM FOR THE FRANCE AND GERMANY ELECTRICITY SERIES

$$\Delta Y_t = \alpha'\beta\, Y_{t-1} + A\ \Delta Y_{t-1} + \varepsilon_t$$

		Dependents Variables	
		$\Delta LGER_t$	$\Delta LFRA_t$
α		-0.0389*** (0.006)	-0.0042 (-0.605)
$EC_{t-1} = \beta' Y_{t-1}$		$\beta' = \left[1, \underset{(0.12)}{-1.104^{***}}\right]$ $Y_t' = [LGER, LFRA]$	
Constant in EC_{t-1}		0.436 (0.498)	
$\Delta LGER_{t-1}$		0.178*** (0.0037)	-0.070* (0.044)
$\Delta LFRA_{t-1}$		-0.086 (0.054)	0.118*** (0.402)
$\bar{R}^2$		0.097	0.012
LR test	$\beta' = [1, -1]$	0.550 *p-value* = 0.458	
	$\alpha_i = 0$	40.993*** *p-value* = 0.000	1.315 *p-value* = 0.518

*,** and *** stand for the significance levels at the 10%, 5% and 1% thresholds, respectively.

Empirical results reported in Table 8 show that the two tests statistics, λ_{trace} and $\lambda_{\max}$, support the hypothesis of cointegration between the three electricity markets with only one long-run relationship.

TABLE 8: RESULTS OFTRIVARIATECOINTEGRATION TESTS

	GER-FRA-ITA	
	λ_{trace}	$\lambda_{\max}(r, r+1)$
$r = 0$	49.39*	42.01
$r = 1$	7.38	6.07
$r = 2$	1.31	1.31

Critical values for the trace test are equal to 29.68, 1541, and 3.76 for *r=0, r=1,* and *r=2* respectively. Critical values for Max-eigenvalue test are 20,97, 14.07, and 3.76 *r=0, r=1,* and *r=2* respectively.

The long-run relationship between the German, French and Italy electricity prices defined by the equilibrium vector error correction model (VECM) is reported in Table9.Theerror correction coefficients associated to the $\Delta LGER_t$ and $\Delta LITA_t$ equations are negatives and significantly different from zero, indicating only the Germany and Italy prices adjusting to deviations from equilibrium. For the $\Delta LFRA_t$ equation, the error correction coefficient is positive and non-significant. Concerning the β vector, empirical results show that only the coefficient associated to $LITA_t$ is non-significant, it is equals to 0.114.

Turning now to the short run dynamics, the estimated coefficients associated to the $\Delta LGER_{t-1}$, $\Delta LFRA_{t-1}$ and $\Delta LITA_{t-1}$ variables are reported in lines 6-8 of Table 9. Empirical results show that the coefficients associated to the $\Delta LITA_{t-1}$ variable in all the three equations are non-significant. This means that the Italy electricity market has no impact on the Germany and French electricity markets neither in the long-run, nor in the short run. For the Germany equation, only the coefficient associated to the $\Delta LGER_{t-1}$ variable is significantly different from zero, meaning that the Germany market is the leader market and is not influenced by the others markets. Finally, the coefficients associated to the $\Delta LGER_{t-1}$ and $\Delta LFRA_{t-1}$ variables are significantly different from zero.

TABLE 9: ESTIMATION OF THE VECM FOR THE GER, THE FRA AND ITA SERIES

$$\Delta Y_t = \alpha'\beta\, Y_{t-1} + A\ \Delta Y_{t-1} + \varepsilon_t$$

		Dependents Variables		
		$\Delta LGER_t$	$\Delta LFRA_t$	$\Delta LITA_t$
α		**-0.039***** **(0.006)**	**-0.0003** **(-0.519)**	**-0.0076**** **(-2.138)**
$EC_{t-1} = \beta' Y_{t-1}$		$\beta' = \left[1, \underset{(0.129)}{-1.133^{***}}, \underset{(0.164)}{0.114}\right]$ $Y_t' = \left[LGER, LFRA, LITA\right]$		
Constant in EC_{t-1}		**0.069** **(0.728)**		
$\Delta LGER_{t-1}$		**0.168***** **(0.040)**	**-0.0308***** **(0.012)**	**0.0178** **(0.024)**
$\Delta LFRA_{t-1}$		**-0.080** **(0.064)**	**0.1176***** **(0.040)**	**-0.017** **(-0.847)**
$\Delta LITA_{t-1}$		**0.049** **(0.068)**	**0.106** **(0.080)**	**0.275** **(0.040)**
$\bar{R}^2$		**0.097**	**0.013**	**0.084**
LR test	$\beta' = \left[1, -1, 0\right]$	**1.007** ***p-value*** **= 0.604**		
	$\alpha_i = 0$	**40.727***** **p-value = 0.121**	**1.8016** **p-value = 0.614**	**4.899** **p-value = 0.179**

*,** and *** stand for the significance levels at the 10%, 5% and 1% thresholds, respectively.

Finally, we test for the restriction that $\beta' = \left[1, -1, 0\right]$ and $\alpha_i = 0$. The first restriction is motivated by the fact that the long-run coefficient of LITA is equals to 0.114 and non-statistically significant. Thus, we set this coefficient equals to 0 and in addition we set the long-run coefficient of LFRA equals to 1. Under this restriction, the multivariate long-run relationship corresponds to that of the bivariate long-run relationship reported in Table 7 with a bit difference. The unique difference between the two specifications lies in the $\Delta LITA_{t-1}$ variable which appears in the short term dynamics of the multivariate analysis. Empirical results of the two restrictions are reported in the last line of Table 9. The restriction that $\beta' = \left[1, -1, 0\right]$ cannot be rejected as showed by the LR test, indicating the existence of long run relationship between the LGER and LFRA electricity prices. For the second restriction, like in the bivariate case the hypothesis of $\alpha_i = 0$ cannot be rejected only for the first equation. Moreover, we remark that the inclusion of the $LITA_t$ variable in the long-run dynamics and $\Delta LITA_{t-1}$ in the short-run dynamics does not significantly affects the results compared to the bivariate case.[15]

One of the major limits of the cointegration analysis is the hypothesis of the stability of the β parameter (constant cointegrating vector) over time. To allow for possible dynamics of price convergence over time we employ in the following subsection the state space model presented by equations 5 and 6.

4.4 Time varying β-coefficient

TABLE 10: RESULTS OF TIME VARYING COEFFICIENT MODELS

	Intercept	State coefficient
LGER-LFRA	1.038^{***}	0.995^{***}
	(0.130)	(0.0004)
LGER-LITA	2.987^{***}	0.932^{***}
	(0.243)	(0.0006)
LFRA-LITA	2.321^{***}	0.947^{***}
	(0.209)	(0.0005)

Standard errors and RMSE are in parenthesis (.), respectively for the intercept and the state coefficient.

*,** and *** stand for the significance levels at the 10%, 5% and 1% thresholds, respectively.

The use of the time varying state space model to assess market integration process through price convergence is mainly motivated by possible dynamics of price convergence over time. Econometrically, this dynamics is captured by allowing

[15] We note that the all estimated VEC model presented in this paper are stable over the whole period under study. For this end, we have used the CUSUM and CUSUM squared tests. Results about these tests can be obtained upon request from the author.

the β-coefficients to be time varying. Regarding economics, several possible explanations of this behavior can be advanced in empirical literature such as structural changes, common directives, and reforms occurred in these three electricity markets over the last years. The estimation of the space state model has been done using the Marquardt optimization algorithm. Empirical results of the estimated state space model are reported in Table 10. All estimated coefficients are highly significant. In particular, the estimated β-coefficients are all significant and very close to 1.

Figure 2 shows the estimates of the β-coefficient for the pair Germany and France. There is a clear trend of βtowards 1 indicating price convergence. The evolution pattern of the time varying coefficients is almost constant over the considered period, indicating that these markets have moved towards a greater level of markets integration. This result confirms the empirical findings of price convergence between Germany and France prices, see for instance Dijkgraf and Janssen (2007).On the other hand, for the two pairs Germany-Italy and France-Italy, the estimated time varying β-coefficients are also highly significant and close to zero, they are approximately 0.932 and 0.947 for these two pairs respectively. Observing their time varying evolution of the β-coefficients (Figures 3 and 4), we remark that they diminish overtime. This result can be considered as indicator of weak convergence, but not a total absence of integration/price convergence.

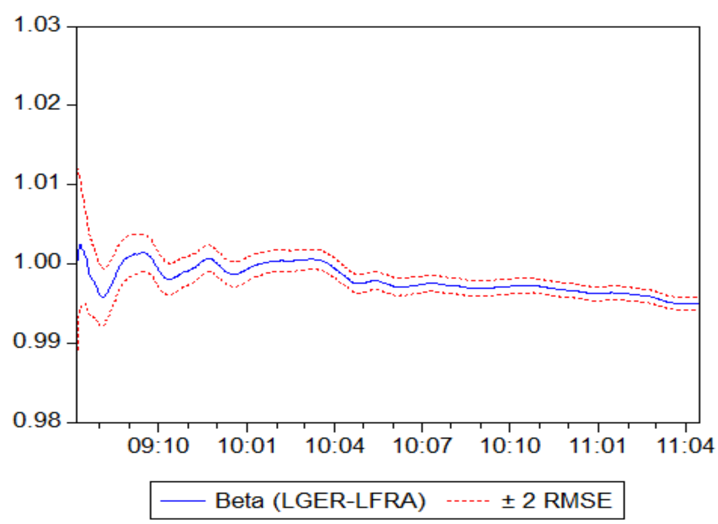

Figure 2: The Time Varying β-coefficient of the pair Germany-France

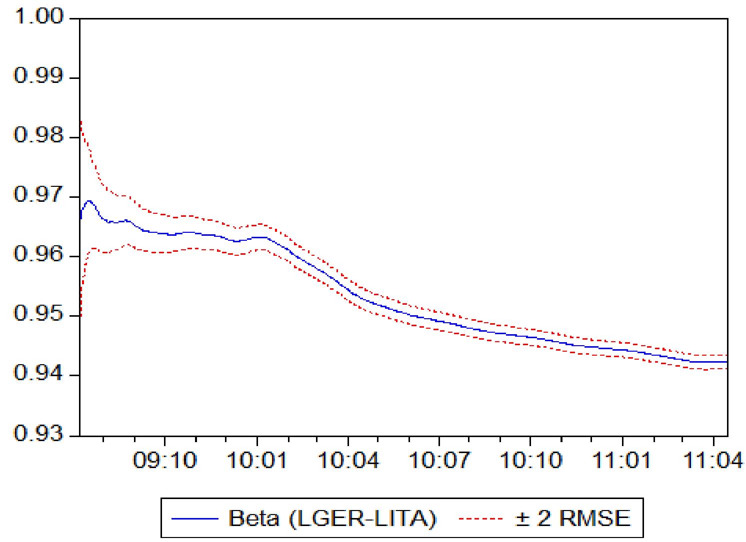

Figure 3: The Time Varying β-coefficient of the pair Germany-Italy

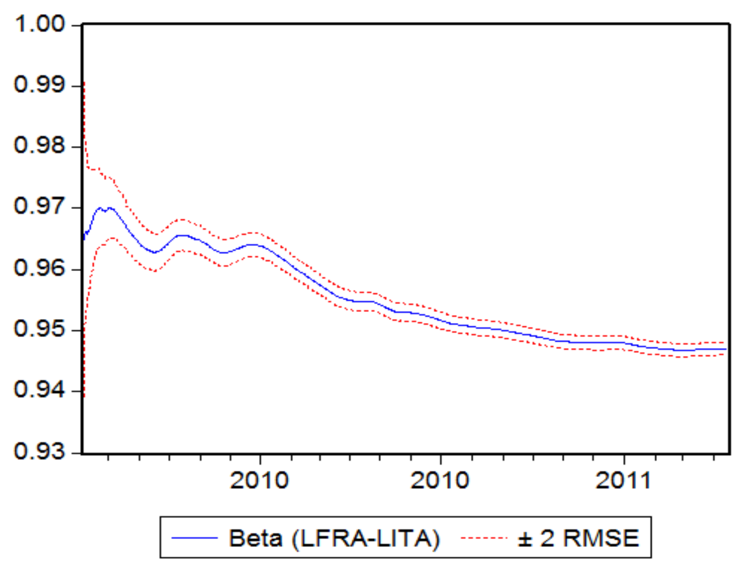

Figure 4 : The Time Varying β-coefficient of the pair France-Italy

5. SUMMARY AND IMPLICATIONS

The creation of a single electricity market throughout the Europe countries is one of the most important objectives of the European Union's priority. To achieve this goal, several reforms have been introduced by the European Union's such as the (98/30/EC) and (2003/55/EC) directives and the recent 2009 energy package. These structural changes have introduced in the attempt to accelerate the pattern of electricity market integration of these countries. In this paper, to investigate empirically electricity markets integration of the three major European countries (Germany, France and Italy), we employed two distinct and complementary methods. First, we use the co-integration technique which assumes a fixed relationship between prices over the considered period. Second, we use a state space specification which assumes dynamic and evolving relationship between prices over time.

The empirical results of the bivariate and multivariate cointegration analysis show that the Germany and French electricity prices time series share a common stochastic trend and that the hypothesis of long-run relationship between these two electricity markets cannot be rejected. Empirical result indicates that these two markets are highly integrated as there is a price convergence between electricity prices of the Germany and French countries. For the two others pairs, the Germany and Italy, and France and Italy, the hypothesis of cointegration is highly rejected suggesting absence markets integration and of price convergence for each pair.

Over all, these results show that the European countries become more interconnected in the last years and especially between Germany and France. This interconnection needs more effort in order to make harmonization between markets. Thus, an increase of the European's economic growth is necessary to lead more markets integration by stimulating investment in energy efficient technologies. The European countries must introduce systems development to support renewable energy. Also, these countries must take into account congestion problems and network capacity as viewed by Regulation 714/2009/EC that will result from new flow patterns in order to accelerate integration process. Moreover, significant investment in network extensions will be required to adequately integrate increased renewable energy and to maintain the supply security. Another challenge for the Europeans countries is to evaluate the impact of the electricity industry reform on consumers satisfaction and the determinants of residential electricity prices.

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