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European power markets–A journey towards efficiency

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ABSTRACT

The liberalization process of European electricity markets has been a work in progress since early reforms beginning in the 1990's. A key goal of these reforms was to enable increased integration and attendant efficiency within these markets. In this paper, we analyse three major European electricity markets - (APXUK, NordPool and Phelix) – before and after the 2009/72/EC Directive was introduced, to examine the extent to which those markets are efficient and whether they have become more integrated. We find little evidence of significant long run relationships between the different markets. We also find that the NordPool and Phelix markets in particular exhibit volatility persistence and clustering behaviour that is inconsistent with the postulations of market efficiency. The existence of continued inefficiencies across these power markets indicates that the desired goal of achieving an efficient and unified electricity market in the EU context is still a work in progress.

1. Introduction

The deregulatory process for European electricity markets that began in the 1990s was intended to allow for the introduction of competition in monopolised market structures. The economic rationale behind the deregulation of power markets was the need to stimulate and facilitate competition among electricity market participants and to bring a higher degree of efficiency to the markets (Vasconcelos, 2009). The creation of a single integrated energy market is one of the building blocks of the EU's broad energy policy, which is concerned with sustainability, competitiveness, security of energy supply, and also to the development of cross border trade in electricity that addresses the scarce interconnection of electricity capacities across Europe (Rademaekers et al., 2008).

The EU faces major challenges regarding the physical interconnectivity between its constituent energy markets, and also in terms of concentration levels which are a major area of concern for policy makers and energy regulators. The high levels of concentration in the electricity markets have caused scepticism among large energy consumers that question the existence of fair competition in the formation of prices on the spot and forward wholesale markets. It is argued that market liberalization and integration can stimulate increasing levels of security of supply, while also time promoting lower energy prices in the long run. However, in the short run many challenges may persist, including the potential for undersupply and poor quality of service.

Understanding market connections and their level of integration and efficiency across Europe would offer important insights in terms of market competition, market organisation and the identification of benefits that the liberalization of power markets might bring to Europe. From an analytical point of view, Joskow (2006c) argues that there are three main approaches for examining the effects of liberalization reforms. These are: (i) “before and after” studies using time series data; (ii) inter-country and inter-state comparisons where liberalization instructions vary from country to country or state to state; and (iii) structural simulation approaches. In this paper we adopt the first approach whereby we examine whether and to what extent the selected European power markets have become more efficient following the introduction of the 2009 EU electricity directive. By looking at power market dynamics through an analysis of daily spot prices, this study seeks to identify potential signs of market efficiency by testing for random walks, the existence of long run relationships, volatility persistence and clustering behaviour in the wholesale electricity prices across the three major European power exchanges.

The main contribution of this paper is a focused discussion and analysis of some of the most developed European power markets in the context of price market efficiencies after the introduction of the latest EU electricity directive. A further contribution of this paper is the application of a key combination of econometric models that allow us to robustly derive inferences about the consistency of research findings in this area and to resolve potential conflicts that arise from the use of different research methodologies. This is an issue that to our knowledge has not been sufficiently addressed in the extant literature. The remainder of the paper is structured as follows: Section two offers a general overview of the European power markets. Section three

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presents the data and proposed research methodology. Section four outlines the main results and attendant discussion and section five concludes.

2. An overview of European power markets

In this section we trace the reforms designed to develop the European power markets. We also look at some of the basic characteristics of an efficient market as it pertains to the electricity context.

2.1. The reform of power markets across Europe

Over the past two decades, the structure of European energy markets has been undergoing major reform with a view to moving towards a single integrated market. This process is characterised by high levels of complexity due to technological, environmental and geo-political factors associated with the different countries and regions. Indeed, these factors play a major role, as they add extra barriers to the unified approach that the EU has taken regarding its energy policy. The integration process has been orchestrated by the European Commission which has tried to encourage individual member states to progress towards a broader and more open perspective as opposed to one solely focused on national interests (Karan and Kazdagli, 2011). The outlined EU directives are designed to enhance competition via better functioning of the markets as a whole, rather than the fragmented and incoherent manner in which these markets have operated heretofore (Sioshansi, 2006). More integrated markets should increase efficiency and this in turn should facilitate lower electricity prices as compared with separate and individually run markets (Ehrenmann and Neuhoff, 2009). Another issue of importance is the need to reduce the influence of national monopolies with the purpose of improving the supply and stability of the sector, as countries would be able to cooperate through their interconnected systems helping them to become more integrated. Through market integration, countries that experience high-variable costs in their generational capacity should be able to obtain positive welfare gains. In this regard, the liberalization and integration process is characterised by a dynamic process of discovery, and continuous interactions between the different market players and the regulatory authorities. The process of market liberalization has also contributed to an increase in trading activity across Europe, where wholesale power trading is dominated by over the counter markets (OTCs). These markets have gained in importance in terms of the negotiation of energy products and derivatives trading as evidenced by substantial increases in prices and volume risks. Through the intensive market activity that is being registered across power markets, market competition should be enhanced with an attendant increase in market efficiencies.

2.2. Towards an efficient power market

The key issues for energy markets in attempting to address market inefficiencies have been identified as the liberalization, privatization and restructuration of the energy supply and distribution industry. In the particular case of the EU the need to reform energy markets became acute due to its heavy dependence on oil and gas from external sources. Therefore, the need to develop an energy sector that is more integrated and competitive and where national energy models co-ordinate more closely in the development of strategic policies that are aligned with current market trends has become a major priority (Karan and Kazdagli, 2011). The initial stages of market reform in the EU can be found on the British and Nordic electricity markets which were made with the goal of creating a unique energy market (Kroes, 2007). The creation of an efficient and unique energy market structure is supported by four major pillars as described by Pollitt (2009a): The first stage is the privatization of publicly owned electricity assets; this is followed by the opening up of the market to competition; the extension of vertical unbundling of transmission and distribution from generation and retailing; and finally, the introduction of an independent regulator. Some of the major challenges associated with the whole process are the combination of political and economic barriers that have negative impact and that give rise to divergences across countries. To address these issues, the European Commission (2010b) envisaged a single European approach to integration rather than a regional one (Directive 25009/75/EC, 2009).

2.3. Price dynamics in power markets

Trading activities in power markets are associated with large amounts of information. Understanding these activities requires an in-depth knowledge of utility markets and the information systems they support. In this regard, the dynamics of how historical information is managed and the level of efficiency that these markets exhibit is key, due to the implications of having official market prices that are transparent and that offer all available information at trading times to market players (León and Rubia, 2004). Price fluctuations in energy markets are clearly associated with profit opportunities to investors, but they are also linked to high levels of risk. The main characteristic of electricity relates to its limited storability, making it difficult to insure against price risks by building appropriate reserve levels. Fluctuations in electricity demand and supply which is affected by weather conditions and/or failures of power plants respectively lead towards the generation of extremely high costs. Additionally, the inelasticity of electricity demand creates major jumps or spikes in prices that are frequently followed by a quick return to normal price levels. This type of behaviour is a particular feature of spot prices in most electricity markets, as are the associated high volatility levels. Price movements are also conditioned by the patterns exhibited by economic and business activities. Therefore, electricity prices reveal cyclical patterns that account for markets needs which are closely linked to human activity and to climate conditions. Electricity prices are further characterised by their complexity, as they are affected by seasonal behaviour, mean reversions, and major shocks which translate into extreme price fluctuations (Paraschiv, 2013).

Following the idea of price formation under conditions of *"market efficiency"*, price changes should behave in a random fashion and should not exhibit serial correlation to allow the incorporation of all available information to the market. Thus, price behaviour and their level of efficiency need to be studied to identify if prices in power markets exhibit a trend and whether the identification and predictability of patterns is possible on power exchanges. In addition, further analysis of price efficiencies in EU power markets is of importance, given the nature of existing research which has shown some inconsistency in terms of the results which has been linked to both methodology and research sample periods. For example, advanced models tend to confirm the existence of market efficiency, while older research techniques are more inclined to reject it. In general, it would appear that energy and power markets are not especially efficient, and this is an issue of concern when understanding the real impact that energy directives are having on electricity price formation (Avsar and Goss, 2001). Therefore, understanding the implications and impact of energy directives on electricity price behaviour is a significant matter. Policy makers should be able to identify tools that help them analyse the impact of implemented directives with a view to ensuring that markets dynamics are moving closer to expectations.

3. Data and methodological framework

Daily spot electricity prices are analysed for the period September 2004 to September 2014, for the Nordic region (NordPool), the UK (APX/ICE) and Germany (EEX/Phelix) – the dataset includes 2620 observations per each market under analysis.[1] The research sample is

[1] See the following for more detailed information:.

divided between two main periods, with a breakpoint based on the date of the introduction of the 2009/72/EC Directive (13th July 2009). The series are tested for efficiency through the assessment of their stationarity, cointegration and volatility properties to establish whether there is predictability in the price series or if they are characterised by random walk behaviour.

3.1. Data description

3.1.1. Basic structure of examined power markets

The Nordic power market is characterised by over twenty years of successful operation and by its increasing connection to continental markets. It utilises a mix of electricity generation sources: Hydro, wind, nuclear and thermal power. The German power system generation sources are based on nuclear, lignite, coal, natural gas, oil and derived gas. In the case of the UK the mixture of generation sources is mainly fossil fuels and nuclear and renewable energies. Both APXUK and Phelix have a strong connection with fossil fuels with a representation of 55% for Germany and around 60% for the UK as the main generation sources to fuel energy plants. This fact should be considered when analysing the research outcomes, as NordPool might exhibit different patterns than its counterparts. NordPool has a longer history regarding market integration processes, and its energy generation sources are mainly supported by renewable energies in clear contrast with the case of Germany and the UK. These markets were chosen given their liquidity and because they are some of the most long-standing electricity futures contracts available. Liquidity on all three contracts has grown substantially since their inception and the open interest ranges from 1 to 10 terawatt hours (TWH) per day.

3.1.2. Data transformation arguments

To incorporate seasonality and mean reversion, the spot price is expressed as a combination of two components:

$$P_t = f_t + \sum_{i=1}^{n} X_{i,t} \tag{1}$$

Where f_t is the deterministic component of seasonality and $X_{i,t}$ is stochastic. In this regard, logarithms should not be used on de-seasonalised spot prices as de-seasonalising day-ahead spot prices can lead to a negative residual. Also, levels of prices appear to yield better parameter estimates. A brief review of existing research analysing energy price dynamics in the context of market cointegration, integration, uncertainty and efficiency shows contrasting views regarding the kind of data transformation that is required to model electricity price behaviour. The data type and the kind of transformation to be implemented is dictated by two central factors. The first relates to the research framework under consideration, as selected modelling techniques will direct the type of data transformation that is required. The second factor relates to researchers' preferences and their personal alignment with the main body of literature that supports their research studies. For example: data in levels have been used by research developed by Lin, Zhang and Wu (2012), Growithsch and Nepal (2009), Arciniegas, Barrett and Marathe (2003). Logarithms were considered appropriate by Bunn and Gianfreda (2010), and Mjelde and Bessler (2009). Log returns by Cartea and Figueroa (2005). First differences by Weron et al. (2004), three Blocks/day by León and Rubia (2002) among other types of transformations, where the use of data in levels and logarithms seem to be the dominant trend in the field.

As there is no consensus among existing research studies in the field, the approach followed in this paper is based on the use of levels of prices and logarithms (identified as the most common data transformations to model energy prices) as it allows us to identify potential divergences using the outlined econometric framework and to study price efficiencies in power markets. The price series considered are daily market prices that are transformed into natural logarithms when required to facilitate the performance of some of the selected econometric models.

3.1.3. Understanding market efficiency

The meaning of market efficiency can be traced back to Fama's Efficient Market Hypothesis (EMH) (1970, p.383) which stated that: *"A market in which prices always 'fully reflect' available information is called 'efficient'"*. In an efficient market, it is not possible to predict prices as they behave in a random fashion. Thus, the more efficient the market is, the more random the sequence of price changes, eliminating any potential of forecasting opportunities. As a result, no investment pattern could be discerned, and a planned approach to investment would not be successful, as "random walk" prices will result in failure of any investment strategy that aims to beat the market consistently. However, it is important to note that EMH does not dismiss the possibility of market anomalies that can yield superior profits. Therefore, deviations from the fair price are considered random fluctuations themselves, and as such investment strategies that result in beating the market cannot be identified as a consistent phenomenon. The concept of "weak form" market efficiency comprises historical prices only, and it means that there is no possibility of earning superior risk adjusted profits based on past prices (Shleifer, 2000), an outcome that leads to the random walk hypothesis. Testing for a random walk which is equivalent to testing for weak form efficiency is important in the context of power markets, as it also allows us to differentiate between predictable and unpredictable components which in turn allow for the identification of future trends in prices behaviour.

Since a homogenous commodity (electricity in our case) is traded at the wholesale spot, futures and forward markets, efficient and liquid markets should not provide significant price differences across the different markets (law of one price or no-arbitrage argument). In efficient markets, the availability of new market information is incorporated immediately into the prices. However, the processing and interpretation of new information into prices may take place at different speed and magnitude. Differences in these parameters can be attributed to differences in market efficiency. Thus, when comparing two markets, the (more) efficient one will be a price leader for the less efficient market (price taker) in the price discovery process (Growitsch and Nepal, 2009). Moreover, if a market is identified as weak form efficient, prices should follow a random walk, indicating that price changes are independent and not related to each other, and that historical information is fully and instantaneously reflected in current prices. The context of the efficient market hypothesis considers that prices are rationally based and that price changes should be random and unpredictable as they adjust and react to new information that by its very nature is unpredictable, and as such, prices are said to follow a random walk. Therefore, the existence of correlations between market returns is seen as evidence that the markets do not follow a random walk and they may be considered to be inefficient on that basis. Such market behaviour eliminates the potential for abnormal gains on the basis of historical information, as per Fama's (1970) discussion on market efficiency. In this regard, market prices should be uncorrelated to ensure that prices behave randomly. This was the main issue under consideration when selecting the appropriate research methodology to support this study and that is outlined in the section that follows.

3.2. Research methodology

We test for market efficiency using a variety of econometric models to allow for an in-depth comparison and to ensure robustness in the results. Firstly, we use the Augmented Dickey-Fuller (ADF) unit root

(*footnote continued*)
http://www.apxgroup.com/trading-clearing/apx-power-uk/.
http://www.nordpoolspot.com/How-does-it-work/Day-ahead-market-Elspot-/.
https://www.eex.com/en/products/power/power-derivatives-market.

test (Dickey and Fuller, 1979) to examine the existence of weak form efficiency on prices, and the analysis is followed by the implementation of additional tests as outlined below.

a) A traditional unit root test was chosen and implemented. The Augmented Dickey-Fuller (ADF) test was selected to test for the existence of weak form efficiency.

$$\Delta y_t = \alpha y_{t-1} + x_t'\delta + \beta_1 \Delta y_{t-1} + \beta_2 \Delta y_{t-2} + \ldots + \beta_p \Delta y_{t-p} + \upsilon_t \tag{2}$$

where y_t is a series that follows an autoregressive process of order p, x_t are optional exogenous regressors that would consider the inclusion of a constant and/or a trend, α, β *and* δ are parameters to be estimated and υ is the error term that is assumed to be white noise. The null hypothesis is the presence of a unit root or non-stationarity. Non-rejection of the null hypothesis would imply that the series follow a random walk and it will confirm the potential existence of a weak form of market efficiency on the energy prices under study.

b) Kwiatkowsky, Phillips, Schmidt, and Shin test (KPSS) is used as an alternative unit root test (Kwiatkowski et al., 1992), where the null hypothesis of stationarity is tested against the alternative of a unit root. The KPSS test acts as a complementary unit root test in this analysis, with the aim of strengthening the results from the ADF test outlined above. Similarly, the rejection of the null hypothesis would indicate that the market follows a random walk hypothesis, and consequently, the market would be found to be weak form efficient. The KPSS test statistic is based on the analysis of the residuals from the OLS regression of y_t on the exogenous variable x_t that is represented in the equation below.

$$y_t = x_t'\delta + \upsilon_t \tag{3}$$

An LM statistic defined as $LM = \frac{\sum_t S(t)^2}{T^2 f_0}$ is computed using the residuals of the OLS equation in order to test the null hypothesis for stationarity. As indicated, the selection of an additional unit root test is based on the need of cross-checking results to ensure that the research outcomes show some level of consistency.

c) The Ljung-Box Q-Statistic test (Ljung and Box, 1978) is used in this study to develop a comparison with the Variance Ratio analysis (see details of the test below). The Ljung-Box Q-Statistic tests the joint hypothesis that all the autocorrelation coefficients up to a defined lag (m) are simultaneously equal to zero. This test checks for the existence of high-order serial correlation in the residuals.

$$Q = n(n+2)\sum_{k=1}^{m}\left(\frac{\rho_k^2}{n-k}\right) \tag{4}$$

where; n is the number of observations, m is the number of lags and ρ_k is the autocorrelation coefficient at lag k. Q follows a χ^2 distribution with m degrees of freedom. This test will help to verify if the outcomes of the variance ratio test support random walk behaviour and consequently aligns with the concept of "weak-form efficiency".

d) The Variance Ratio test is implemented to support the unit root tests discussed above. The existence of a unit root is not considered sufficient to confirm that markets behave as random walk, as unit root processes can have predictable elements. This is a good and sufficient reason that justifies the inclusion of two-unit root tests that help cross-checking and confirming research outcomes. However, for prices to be considered random their returns must be found to be uncorrelated. Therefore, we test the random walk hypothesis using the Lo and MacKinlay (1988) variance ratio (VR) test. The VR test is based on the assumption that the variance of a random walk term increases linearly with time. We have selected this test, as it has become a standard tool in the testing for random walk processes and research studies that have focused on the analysis of the EMH (Lo and MacKinlay, 1989).

$$VR(q) = \frac{\sigma^2(q)}{\sigma^2(1)} \tag{5}$$

where; $\sigma^2(q)$ is the unbiased estimator of $(1/q)$of the variance of the *q-th* difference and $\sigma^2(1)$ is the variance of the first difference. Under the assumption of homoskedastic increments, a standard normal statistic $z(q)$ is calculated as follows:

$$z(q) = \frac{VR(q) - 1}{\sqrt{v(q)}} \sim N(0, 1) \tag{6}$$

where; $v(q) = [2(2q-1)(q-1)]/3q(nq)$. A second test statistic $z^*(q)$is developed under the assumption of heteroskedastic increments as follows:

$$z^*(q) = \frac{VR(q) - 1}{\sqrt{v^*(q)}} \sim N(0, 1) \tag{7}$$

where;

$$v^*(q) = \sum_{k=1}^{q-1}\left[\frac{2(q-k)}{q}\right]^2 \phi(k) \tag{8}$$

$$\phi(k) = \frac{\sum_{t=k+1}^{nq}(p_t - p_{t-1} - \hat{\mu})^2(p_{t-k} - p_{t-k-1} - \hat{\mu})^2}{\left[\sum_{t=1}^{nq}(p_t - p_{t-1} - \hat{\mu})^2\right]^2} \tag{9}$$

Both the $Z(q)$ and $Z^*(q)$ statistics test the null hypothesis that $VR(q) = 1$ or the chosen index follows a random walk. When the random walk hypothesis is rejected and $VR(q) > 1$, and the returns would be positively serially correlated, indicating that the markets are inefficient. The Variance Ratio approach was selected because it focuses its attention on the uncorrelated residuals, an approach that is widely used when dealing with none normally distributed series (Chow and Denning, 1993).

e) Market Integration analysis is used to identify if the selected power markets display the same risk-adjusted expected returns. In the case that markets are found to be segmented, the risk-return relationship in each national market would be determined by domestic factors, and there would not be evidence of international effects. Pure random walks cannot be cointegrated, unless they are perfectly correlated. To the extent that market efficiency is interpreted to mean that prices are random walks, the arguments that prices in efficient markets cannot be cointegrated would be correct. If two-time series are found to have the same order of integration and if a linear combination of these series exist that is stationary (integrated of order one), these series would be referred to be cointegrated (Granger, 1986). Engle and Granger (1987) proposed a two-step procedure to estimate cointegration. In this two-step procedure, the first series (y_t) is regressed on the second series (x_t) and the resulting error (e_t) is tested for stationarity. If the null hypothesis of non-stationarity is rejected, it can be said that the time series are cointegrated. Cointegration implies that both series would move together in the long-run and they cannot drift apart very much from each other (Granger, 1981).

$$y_t = \alpha + \beta x_t + e_t \tag{10}$$

An alternative test for cointegration is based on a vector autoregressive (VAR) model. The vector X_t contains the endogenously seen variables and has the dimension $n\,x1$, where n is the number of endogenous variables. Each variable follows a process that is influenced by its own lagged variables and the lagged variables of the other endogenous variables.

$$X_t = \prod\nolimits_1 X_{t-1} + \ldots + \prod\nolimits_k X_{t-k} + \mu + \varepsilon_t \quad \text{with } t = 1, \ldots, T \tag{11}$$

The matrix of coefficient Π_k has the dimension $n\,x\,n$. Based on the equation above; the VAR can be transferred to a VAR of first differences. For this purpose, the lagged variable of the endogenous variables are subtracted from both sides and the system below arises.

$$\Delta X_t = \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \prod_k X_{t-k} + \mu + \varepsilon_t \tag{12}$$

where, $\Gamma_i = -I + \Pi_1 + \ldots + \Pi_i$ with $i = 1, \ldots, k-1$ and $\Pi = -(I - \Pi_1 - \ldots - \Pi_k)$ (Johansen/Juselius, 1990, p.170). Johansen proposes two tests to determine the cointegration rank, the "trace statistic" and the "maximum eigenvalue test". Both test statistics should be used simultaneously. In this case the researcher should be aware that different conclusions can be drawn from the tests, and that the Johansen test does not allow the identification of the specific variables that are found to be cointegrated. The estimation of the parameters for the cointegration vector, adjustment coefficients or eigenvalues is done through the Maximum Likelihood Procedure.

f) The Autoregressive Distributed Lag (ARDL) cointegration technique or bound cointegration technique is applied to support the analysis on long run relationships, as this technique is preferable when dealing with variables that are integrated of different order I(0) or I(1) and even a combination of both. Pesaran and Shin (1996), and Pesaran et al. (2001) indicate that cointegration techniques have become the solution to determining the long run relationship between series that are non-stationary, as well as reparametirising them to the Error Correction Model (ECM). Testing for cointegration is a necessary step to establish if a model empirically exhibits meaningful long run relationships, and in the context of this study to help understanding if electricity prices in the European context follow a similar trend, or can be forecasted or predicted. Unlike the Johansen and Juselius (1990) cointegration procedure, the ARDL approach helps identifying the cointegrating vectors. Furthermore, the ARDL has three main advantages when compared to traditional cointegration methods: 1) it does not need that all the variables under study should be integrated of the same order. 2) It is an efficient test in the case of small and finite data sizes. 3) And, unbiased estimates are obtained for the long-run model. This test was implemented as the Johansen and Juselius (1990) estimation could not be performed due to differences in levels of integration among the series. A general ARDL (p,q) as Pesaran and Shin, p.372) (1998) can be written as:

$$y_t = \alpha_0 + \alpha_1 t + \sum_{i=1}^{p} \varphi_i y_{t-i} + \beta' x_t + \sum_{i=0}^{q-1} \beta_i \Delta x_{t-i} + \mu_t \tag{13}$$

$$\Delta x_t \quad = P_1 \Delta x_{t-1} + P_2 \Delta x_{t-2} + \ldots + P_s \Delta x_{t-s} + \varepsilon_t \tag{14}$$

where x_t are the k-dimensional I(1) variables that are not cointegrated among themselves, μ_t and ε_t are serially uncorrelated disturbances with zero means and constant variance-covariances, and P_i are $k\ x\ k$ coefficient matrices such that the vector autoregressive process in Δx_t is stable.

g) The Analysis of Volatility persistence in the selected power exchanges was conducted with the support of the traditional GARCH (1,1) model. A commonly random walk model used in finance and that is defined through the equation below,

$$Y_t = \mu + Y_{t-1} + \varepsilon_t \quad \text{where } \varepsilon_t \sim (0,\ \sigma_t^2) \tag{15}$$

ε_t, t = 1,…, are serially independent. If $\alpha = 1$ then $\{Y_t\}$ follows a random walk model and an AR(1) model otherwise. The fundamental idea of the GARCH (1,1) model (Bollerslev, 1986) is to describe the evolution of the variance as σ_t^2,

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \tag{16}$$

The parameters satisfy $0 \le \alpha \le 1$, $0 \le \beta \le 1$,and$\alpha + \beta \le 1$.The variance process is stationary if $\alpha + \beta < 1$, and the stationarity variance is given by $\frac{\omega}{1-\alpha-\beta}$. The parameter $\eta = \alpha + \beta$ is known as persistence and defines how slowly a shock in the market is forgotten. In the case that the $\alpha + \beta$ coefficients are close to one, the results would indicate process that are long lived and that would be associated with markets that are not aligned with efficiency behaviour, as they would be exhibiting clustering and long-lasting patterns of market uncertainty.

Price formation in wholesale electricity markets is categorised by the instantaneous nature of the product, and the literature highlights characteristics of mean-reversion to a long-run level (Johnson and Barz, 1999), multi-scale seasonality (intra-day, weekly, seasonal), calendar effects, erratic extreme behaviour with fast-reverting spikes as opposed to "smooth" regime switching patterns (Kaminsky, 1997), non-normality that is reflected on positive skewness and leptokurtosis, and excessive volatility with higher magnitudes than the ones exhibited by commodities and financial markets (Escribano et al., 2011). The selection of a variety of econometric techniques constitutes a strong methodological framework that helps modelling electricity prices which are characterised by significant complexity. The econometric models employed in this study ensure that sufficient results are generated that allow us to document and identify consistency regarding the potential evidence of electricity prices aligning with random walk patterns. They also facilitate an in-depth discussion with regard to the existence of market efficiencies in the selected power exchanges before and after the third EU directive was introduced. The ADF and the KPSS tests were considered as they are well known methodologies to test for the existence on unit roots in time series. In the case where electricity practices follow a random walk process, the ADF and KPSS test should report evidence of non-stationarity processes. These tests are supported by the analysis of autocorrelation coefficients (Q-test) that would help clarifying if electricity prices are uncorrelated, a result that would support prices behaving as a random walk. The variance ratio framework is introduced as it is a well establish research methodology to test for market efficiency. The inclusion of cointegration techniques is justified by the significant number of studies that have been developed over the years where cointegration techniques are used to find evidence of long-run relationships among markets that help identifying prices predictability and questioning the existence of market efficiencies based on random walk behaviour. Finally, the GARCH framework was incorporated to look after evidence that might confirm the existing of volatility clustering on electricity markets and that will suggest that prices are not following a random walk and consequently will question the existence of market efficiencies.

4. Results

4.1. Descriptive analysis

Spot prices and returns offer some interesting insights in terms of the basic properties that help to describe the series behaviour. To begin, we can confirm that the series patterns align with the general characteristics of electricity prices in terms of major price spikes, high volatility levels and mean reverting behaviour. Fig. 1 below shows significant levels of price fluctuations followed by clear mean reverting behaviour over the ten-year period covered by the research sample. The case of Phelix is quite interesting as it differentiates substantially from the behaviour exhibited by both the NordPool and APXUK markets in terms of volatility. From Fig. 2 we can see that the series fluctuations are clearly dominated by Phelix which registered the highest positive and negative changes on realised returns.

The descriptive statistics presented in Table 1 below are consistent with the initial analysis of the plotted prices and returns. The Phelix market is associated with higher levels of uncertainty and consequently unpredictability, as indicated by its higher standard deviation, while NordPool appears to behave in a more stable manner when compared with APXUK and Phelix. Looking next at the respective coefficients of

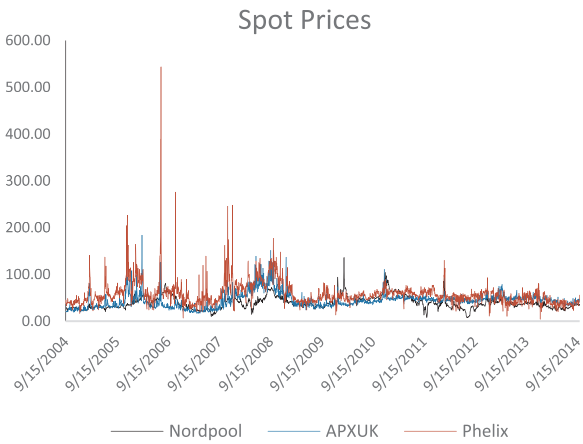

Fig. 1. Spot prices 2004–2014.

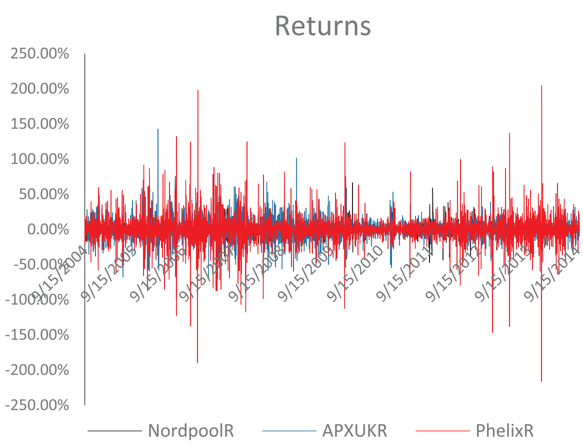

Fig. 2. Returns 2004–2014.

Table 1
Descriptive statistics – before and after 2009/72/EC.

Statistics	Before Directive			After Directive		
	AXPUK	**NordPool**	**Phelix**	**AXPUK**	**NordPool**	**Phelix**
Mean	0.037%	0.010%	0.016%	0.016%	0.0023%	0.014%
Std. Dev.	19.35%	7.08%	25.85%	10.72%	8.53%	20.73%
Skewness	0.34	−0.23	0.01	0.015	0.574	−0.146
Kurtosis	7.35	14.92	11.86	6.23	13.19	25.78
Jarque-Bera	1016	7460	4116	593	5970	29473
CV[a] (Coefficient of Variation)	50.95%	32.83%	51.42%	17.31%	34.53%	23.20%

[a] CV calculated using data in levels.

Table 2
Correlation matrix – before and after 2009/72/EC.

Correlation Matrix	Before Directive			After Directive		
	AXPUK	**NordPool**	**Phelix**	**AXPUK**	**NordPool**	**Phelix**
AXPUK	1	0.5016	0.6205	1	0.2810	0.3549
Nordpool	–	1	0.4528	–	1	0.4773
Phelix	–	–	1	–	–	1

variation, Phelix and APXUK are associated with similar levels of relative variability, while NordPool is the least variable as compared to the other two series. It also demonstrates substantial variability over the two periods. Electric power production in Norway is almost 100% hydropower, while Finland and Sweden are more diversified using hydropower, nuclear, and fossil-fuel-powered generation plants, a situation that allows for more flexibility in the production process and that could explain why NordPool behaved in a more stable manner over the period of study. (Tables 2 and 3)

Interestingly, after the introduction of the third EU Directive, NordPool exhibited higher levels of relative variability which have also increased when compared to the previous period, while its counterparts have faced a substantial reduction on their variability levels. This result seems to suggest that the third EU electricity Directive is having a positive impact regarding the reduction of price variability in the APXUK and Phelix series, whereas in the case of NordPool it impacted negatively.

The analysis of correlations among prices and returns indicate that the series are positively correlated, signalling the potential existence of inefficiencies in the markets, as they do not appear to be behaving in a random walk fashion. When considering the basic principles behind the concept of weak form efficiency (Fama, 1970), price changes should behave in an independent manner whereby historical information is fully and immediately reflected in prices. Interestingly, the correlations among markets decreased after the introduction of the third Directive, and only in the case of Phelix and NordPool was there a slight increase in their correlation. Therefore, the correlation coefficients do not support the idea of market efficiencies; however, they do indicate that positive movements are being made towards efficiency, as this was reflected by the reduction of the correlation coefficients for APXUK-NordPool and APXUK-Phelix after the third Directive was introduced.

4.2. Power markets efficiency analysis

Following our discussion on market efficiency in the previous section, we now consider whether the power markets are weak-form efficient whereby their returns should follow a random walk or non-stationary process. To test for this feature, the ADF and KPSS tests were applied to both sample periods. The ADF and the KPSS offer evidence that the markets are stationary, and that the series do not follow a random walk process, with the single exception of NordPool for the sample period before the third Directive was introduced. The analysis from the autocorrelation coefficients (Q-test) for 36 lags indicate a significant result in all cases, confirming the initial results registered by the correlation and stationarity analysis that show that the markets are correlated and that they do not follow a random walk. The series have autocorrelation functions that diverge from zero with evidence of correlated returns, which is indicative of forecasting potential in those markets. The results from the autocorrelation functions also indicate that the markets are quite dynamic and that adjustment processes are taking place, but that they seem to be quite far from desirable efficiency levels.

The results from both the individual and joint variance ratio tests also indicate that the markets are not following a random walk and that daily returns across the series were positively correlated during both periods. The estimated variance ratios indicate that the markets were inefficient before the introduction of the third Directive and that they remained inefficient afterwards. Taken together, these results indicate that abnormal profit opportunities were available to investors during both periods, but also that high levels of risk were associated with market operations due to the markets inability to achieve an efficient pricing mechanism. The proposed "traditional" cointegration analysis is not appropriate under the current scenario, as in general the series were found to be integrated in levels with only two exceptions: as per the ADF test NordPool was found to be an I(1) process and APXUK was also recorded as an I(1) according to the KPSS result before the introduction of the Directive. After the introduction of the Directive only Phelix was identified as an I(1) process according to the KPSS results.

Therefore, to identify the potential existence of long run relationships across the series an ARDL model of order four was developed, as

Table 3
Econometric modelling results – before and after 2009/72/EC Directive.

Tests/Countries	Before Directive			After Directive		
	AXPUK	Nordpool	Phelix	AXPUK	Nordpool	Phelix
VAR(p) –SC Criteria	4	4	4	4	4	4
ADF	−5.43(0.00)* I(0)	−29.46(0.00)* I(1)	−9.40(0.00)* I(0)	−6.01(0.00)* I(0)	−4.52(0.00)* I(0)	−8.14(0.00)* I(0)
KPSS	0.086(0.73)* I(1)	0.50(0.73)* I(0)	0.41(0.46)* I(0)	0.11(0.46)* I(0)	0.025(0.46)* I(0)	0.031(0.46)* I(1)
Q-test	36(sign)*	36(sign)*	36(sign)*	36(insig)	36(sign)*	36(insig)
VR joint tests	9.99(0.00)*	41.42(0.00)*	150(0.00)*	8.94(0.00)*	3.57(0.00)*	6.32(0.00)*
VR (2,5,10,15)	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*
Johansen	n/a	n/a	n/a	n/a	n/a	n/a
Engle & Granger	n/a	n/a	n/a	n/a	n/a	n/a
ARDL(4)	(P−.1247)	(A−0.4441)	(A−0.8299)	(N−0.3506)	(A−0.5359)	(N−0.0076*)
	(N−0.5931)	(P−.0757***)	(P−.6814)	(P−.0085*)	(P−.0675***)	(A−0.0939***)
GARCH (α)	0.2637*	n/a	0.4305*	0.26577*	0.157342*	0.075402*
GARCH (β)	0.5889*	n/a	0.5483*	0.468925*	0.823371*	0.89068*
GARCH (α+β)	0.8526*	> 1	0.9788*	0.734695*	0.980713*	0.966082*
Half-life volatility	4 days	n/a	32 days	3 days	36 days	21 days

**5% level of significance.

A VAR test was conducted to identify the number of lags to be applied in the selected econometric tests and the Schwarz Info Criterion (SC) was used for the selection. ADF (Augmented Dickey-Fuller Test), KPSS (Kwiatkowsky, Phillips, Schmidt, and Shin), Q-test (Ljung-Box Q-statistic test), VR (Variance Ratio test), Johansen (Johansen Cointegration test), Engle & Granger (Cointegration test), ARDL(4,4) – Autoregressive Distributed Lag Model of order 4; GARCH (Generalised Autoregressive Conditional Heteroskedastic model). The results for the GARCH model were tested for autocorrelation and heteroscedasticity to ensure that they were robust estimations, the results are not presented for the sake of brevity, but they are available upon request.

* 1% level of significance.

*** 10% level of significance.

this model does not impose the need for the series being integrated at the same level, as it is the case for traditional cointegration methodologies. The results show that in general the series do not appear to be moving together in the long run, and in the cases where some evidence was found this was identified to be quite weak, as the level of significance associated with the coefficient was only at the ten percent level. The lack of connection among the series is not surprising, as movements in electricity prices are heavily associated with the characteristics of their national markets, weather conditions, specific legislation, and of course the specific demand and consumption needs of national households and industries. In this regard, the lack of connection among the series also confirms that the different policies introduced in the markets might not be helping in terms of achieving the desired levels of integration and that the markets are still behaving in a segmented manner.

The GARCH framework signals that volatility is highly persistent and exhibits clustering behaviour for Phelix during both periods and for NordPool after the introduction of the Directive.[2] In the case of APXUK, the market appears to be more in line with market efficiency as shocks tend to die away quite quickly. The GARCH results denote the existence of market inefficiencies in the European electricity markets; results that are quite consistent with the outcomes obtained from the conducted tests and that strengthen the research findings. The combined results suggest that in general, the introduction of the third Directive has not helped electricity markets to become more integrated and that the journey towards efficiency is still a major work in progress. However, it is worth noticing that some level of improvement has been achieved, as correlations levels among series have experienced some level of reduction, there has been a positive adjustment in terms of relative variability in price fluctuations. Also, some long run relationships appear to be developing across markets, signalling positive movements towards an integrated electricity market.

4.3. Critical insights

The main aspiration of the EU's energy policy is the creation of a single integrated market for energy that guarantees a sustainable, competitive and secure energy supply that in the long run delivers lower energy prices in the region. A worthwhile and laudable goal, as a common electricity market would help to increase welfare by ensuring security of supply, stimulating competition and reaping the gains from international cooperation through such means as reserves sharing, combining different national consumption and production patterns (Zachmann, 2008). However, electricity is a complex commodity, as dynamic prices exhibit stochastic patterns that are clearly associated with significant levels of uncertainty in terms of the price formation process. Furthermore, market inefficiency, market power, inelastic demand, constrained supply, and consumers' demands fluctuations are just some factors that contribute to the complexity of electricity market price dynamics (Borenstein, 2002).

Taking into account the difficulties associated with the pricing process in power markets, the econometric techniques that were chosen to support this study, allowed for the evaluation of the wholesale market efficiency in terms of price adjustments and their alignment to the concept of efficient market hypothesis. Overall, the research outcomes showed that European electricity markets exhibit inefficient characteristics as reflected by the main empirical findings. Firstly, the outcomes from the stationarity tests indicate that prices do not follow a random walk process. This result is supported by the generated autocorrelation functions and the joint variance ratio tests which showed evidence of correlated returns suggesting the potential of predictability patterns on electricity prices. Secondly, the cointegration results showed a lack of connection among the series, thus flagging the existence of segmented markets. These are characterised by significant levels of volatility and clustering behaviour which help to confirm the lack of efficiencies in the European electricity markets.

Overall, the research findings indicate that the wholesale market in the European context seems to be inefficient. Electricity market reforms appear slow in helping electricity markets to price converge and the studied markets are affected by significant inefficiencies in prices that could be explained by differences in auction processes, risk premiums and divergence in regional market power. The concentration and abuse of market power in the wholesale markets leads to inefficient pricing processes that signal the non-competitive nature of the markets. Encouraging the formation of a competitive wholesale market will help to limit the power of electricity producers that would not be able to

[2] The GARCH model was not stable for the first period under study for NordPool.

exercise market power to control electricity supply, and attendant price via decisions on output. As such, the absence of market power is identified a one of the basic conditions that would lead to the materialisation of an efficient wholesale market. In this regard, the liberalization of electricity markets, followed by major restructuring processes to aid these markets becoming more competitive remains a major challenge in the European context (Growitsch and Nepal, 2009). Obstacles that need to be considered carefully by EU policy makers when developing directives that aim to foster the creation of a common wholesale market for electricity.

5. Conclusions

The analysis of market efficiencies among three of the most developed and well-established European electricity markets (APXUK, NordPool and Phelix) was conducted. The study selected the introduction of the third EU electricity Directive, as the key breakpoint that facilitated understanding if introduced policies and guidelines are helping power markets to move towards an integrated and unified framework and if gains on efficiencies have been achieved on the price formation mechanism. The analysis was supported by a selection of well-known econometric tests; like the Variance Ratio test, cointegration techniques and the GARCH model. The selection of different tests is justified by the need of enhancing the research framework by looking for consistencies and robustness on obtained results. Another issue that was taken into account was divergences and controversies exhibited on the conducted literature review in the field that has shown significant evidence of inconsistencies on results derived from differences on the selection of testing models and research approaches.

The main findings highlight that the selected markets do not behave in a random manner and consequently they fail to align with the principles behind the weak form of market efficiency. This is an important finding in that potential market participants who seek to use the electricity market for investment and hedging purposes may have concerns that elements of predictability are present which could be compounded by asymmetric information effects. These concerns could lead to reduced trust and lower attendant participation. From a policy perspective this is something that could be addressed through greater pricing transparency and measures designed to deepen liquidity. Moreover, governments and policy makers need to be aware of significant differences among the studied European energy markets that are still characterised by being segmented. Thus, the foundations that lead towards more integrated markets have been settled, but European energy markets uniqueness need to be considered cautiously when developing future directives. This research provides additional evidence of the need for action and inquiry in these areas. The studied energy markets seem to behave in a segmented manner and the goal of developing an integrated and unified electricity market in the EU is still a work in progress that requires major efforts from governments and other involved players to ensure that reforms and EU Directives are properly implemented. Future research should consider analysing different frequencies on spot prices and expanding the study to look into forward and future contracts behaviour that help gathering further evidence regarding the impact of EU directives in power markets price formation mechanisms.

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