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Time Relationships among Electricity and Fossil Fuel Prices: Industry and Households in Europe

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ABSTRACT

Cointegration relationships among electricity, gas, oil and coal are explored using panel data models for both the industrial and household sectors in 22 countries in Europe between 1996 and 2013. A shorter period, to account for the allowances market creation in Europe is also considered through a dummy (2005-2013) to capture the absence and presence of the CO_2 price effect respectively. Empirical findings reveal that electricity and fuel prices are non-stationary and cointegrated series. So, the current paper accounts for cross-section dependence when analyzing the electricity-fuel nexus. Results indicate that there exists a stronger long run equilibrium relationship between electricity prices and fuel prices in the industry sector, while both a short and long run equilibrium relationship in the household sector. These differences may be explained by the industry higher resilience in long run contracts within the energy sector and by the fact that households bear a larger share of the cost of taxes and levies.

Keywords: Cointegration, Electricity and Fuel Markets, Industrial and Household Sectors
JEL Classifications: O52, Q02, Q50

1. INTRODUCTION

The European Commission (EC) website[1] related "fossil fuels such as oil, gas, and coal are non-renewable resources that account for around three quarters of the energy consumption in the EU. They are used for the generation of electricity and heat, the powering of transport, and as materials in certain industrial processes." Also, EU is the world's second largest producer of petroleum products, having an oil refining capacity of 16% of the world total. As stated by Kirat and Ahamada (2011), the electricity sector is by far the highest user of fossil fuels and the biggest CO_2 emitter.

Moreover, coal and gas remain key components in the fuel mix of many EU countries, accounting for over half of the EU's electricity needs. Given that a significant amount of power plants and industrial processes will continue to use fossil fuels in the future, the use of carbon capture and storage technology is important in helping to decrease greenhouse gas emissions. Accompanying this process, allowances trading are expanding as well as the consumption of fuel sources, tending to follow markets development and increased living standards towards European countries

In Europe it is clearly in the front line of climate change, being responsible for 60% of global greenhouse gas emissions and much of regional and urban air pollution as stated in Madaleno et al. (2014). It is important to focus within the European group of countries since it has given major steps towards its energy efficiency. The energy mix in the EU has been transformed over the last two decades with a strong decline in coal consumption (by 41%) being offset by a significant increase in use of gas (41%) and

1 http://ec.europa.eu/energy/en/topics/oil-gas-and-coal

renewables (116%) (European Commission Directorate General for Energy, key figures report June 2011)[2].

As verified by ECB (2010) there are heterogeneities between individual Member States explained by national energy mix, fragmented national policies including taxation and other forms of state intervention, illustrated by the variation in relative levels and evolutions of household and industrial prices across member states. It is noticed that all countries had household retail prices that were higher on average than industrial prices. In fact, taxes and levies constitute a much larger share in household end-user prices than in industries. Whereas energy and supply costs are the dominant drivers of industrial end-user prices, household end-user prices have been much more varied than industrial prices. This justifies the need to take a deeper analysis onto the differences existent between the two sectors in terms of cointegration relationships.

In fact, most of previous studies focus on the US market, but there is also a strong relationship between energy prices also in Europe where in the last decade several laws emerged inside electricity markets and with respect to renewables introduction and development as substitutes of non-renewable sources. Electricity is mainly produced by gas, coal and hydro and less with oil. Some energy commodities like oil and natural gas are somehow substitutes, meaning that prices should influence each other. Finally, there is also an increase in the connectivity across electricity markets, turning the European market as a whole an interesting case for analysis. The analyzed countries also depend on consumption of oil, coal and natural gas to keep their current electricity production and living standards.

The current work basically analyses the relation between fuel energy consumption, being the main research question whether there is a long-term relationship between electricity prices and prices of energy commodities like oil, natural gas and coal, accounting, through a dummy introduction, for the effect of allowances trade introduction in 2005. Given that these energy commodities are used as input in electricity production we start from the principle that prices should be related in the long run. For this we study possible cointegration relationships between electricity prices and related energy prices considering a sample of European countries through panel data analysis.

Given the previous existent literature it is still important to know if there is a common pattern of electricity prices and fossil fuel prices between European countries, namely to understand if it justifies a more specific application of energy price policies between industrial and households, and also to know which countries have the greatest potential for reducing fossil energy use. This work intends to study the long-term and short-term cointegration of those specific variables on the mitigation of electricity prices.

2 For example, the countries of Central Europe are particularly vulnerable to supply disruptions and price pressure due to a dominant single supplier (Russia). In the case of Poland and the Czech Republic, good reserves of coal provide a degree of energy security, but their cost of extraction is considerably higher than in countries such as Australia. Furthermore, the EU's determination to reduce carbon emissions has the potential to further erode the affordability of coal as an energy source.

This justifies the need for a deeper understanding with respect to the cointegration relationships which exist among fuel sources and electricity prices as well as the effect of allowances introduction, given that economic rational suggests that allowances and fuel price increases will lead to electricity price increases sooner or later. The econometric approach adopted could give relevant information for the policy making with regard to the timing of policy or regulatory interventions and to the choice of policy price instruments for both industrial and households' consumers.

It is a fact that energy markets influence each other and there is a high common possibility of markets relation, but there still exists the need to know at what extent and statistical significance. Previous literature results show that cointegration between energy markets presents different results depending on the region studied because both electricity and natural gas are regional, with an influence over commodities cointegration. Results also differ with respect to whether the input data are spot and futures prices, because their dynamics changes and no conclusions can be transported among the two. Our study goes further by examining whether spot prices among electricity and fossil fuels are cointegrated using a higher set of countries, panel data methods and a larger time period, accounting also for the allowances introduction effect in the electricity market. Moreover, we do the analysis distinguishing effects among the industrial and household sectors, an analysis that up to this moment hasn't yet been performed. We use the recently developed pool mean group (PMG), fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and dynamic fixed effects (DFE) panel cointegration techniques for both sectors to take into account these possible and in effect existent differences emerge among sectors.

A deeper understanding of the cointegration relationships which may exist in Europe will provide more insights onto policies pursued in these countries and will raise better policies development. The existence of a cointegration relationship provides arbitrage opportunities among the commodities (Bencivenga and Sargenti, 2010) crucial for derivatives pricing which involve couple of commodities and spread options. In terms of policy directions it will be important to take into account the importance of the electricity markets liberalization as suggested by the results. As such, countries in Europe which are only at their earlier liberalization stages should accelerate the process in order to decrease short run effects of fuel over electricity prices. Moreover, renewables penetration in the electricity sector implies that a shift in the generation furl mix from natural gas to wind, solar-thermal and photovoltaic power will increase industrial and household end-user prices. However, increases in previous years will raise industrial prices and lower household prices in the current period (ECB, 2010), turning more interesting the cointegration analysis distinguishing the two sectors.

The rest of the work develops as follows: section 2 presents a brief literature review about cointegration analysis performed within different analysis. Section 3 presents the data used and discusses the employed methodologies. In Section 4 all results are presented and are properly discussed, while Section 5 concludes this work presenting some policy implications.

2. LITERATURE REVIEW

The existent literature which tries to relate electricity with fuel sources from a cointegration relation point of view is vast, but none as far as we are aware took care of a large number of countries and considered both industrial and household sectors separately.

For example, Emery and Liu (2002) concentrate onto the relationship between electricity prices, natural gas and coal in California and Palo Verde, finding that all series are integrated of order one and that cointegration exists in both regions. Other studies which explore the links between fuel sources and electricity are those of Asche et al. (2006), Bunn and Fezzi (2007; 2008), Karan and Kazdagli (2011) and Frydenberg et al. (2014). Asche et al. (2006) examine the degree of integration between energy markets in the UK using Johansen's multivariate cointegrating methods. Using monthly wholesale prices, from 1995 to 1998 they found evidence of cointegration among natural gas, crude oil and electricity prices. Also for the UK market, Bunn and Fezzi (2007) analyze cointegration of electricity, natural gas and allowances spot prices, finding through a vector error autoregressive correction model (VECM) that natural gas and allowances prices jointly influence electricity prices. After, Bunn and Fezzi (2008) extend their analysis to the German market finding significant differences in parameters estimates which were associated to their different gas/coal fuel mixes for electricity production.

Giving background and analysis of European energy markets developments, Karan and Kazdagli (2011) analyzed the stages of energy reform, reporting a recent strong correlation in energy prices between Nord Pool, Germany, France, The Netherlands and Austria. More recently, Frydenberg et al. (2014) investigate the relationship between futures prices of electricity, crude oil, natural gas and coal in the UK, Germany and Nordic countries using daily futures data between 2006 and 2012. Their results point for cointegration between UK electricity, coal and gas and between electricity and coal in Nordic countries.

De Jong and Schneider (2009) used cointegration methods to analyze the joint dynamics of multiple energy spot prices in the UK, Belgium and the Netherlands. The authors conclude that gas prices are strongly cointegrated but that cointegration of gas and power prices only happens in the long-term and for futures. One-year later, Bosco et al. (2010) analyze interdependencies in wholesale European electricity markets (Germany, France, Austria, Netherlands, Spain and Nordic countries) using hourly spot prices averaged to weekly median and by using a multivariate long run dynamic analysis.

In 2009, Mjelde and Bessler studied dynamic price information flows among US electricity wholesale spot prices and the prices of the major electricity generation fuel sources (natural gas, uranium, coal and crude oil). The multivariate time series model which they employed allowed the authors to conclude that in contemporaneous time peak electricity weekly prices move natural gas prices, which in turn influence crude oil. Bachmeier and Griffin (2006) use a VECM to analyze the degree of market integration among crude oil, coal and the natural gas market. Villar and Joutz (2006) use a longer time period (1989 until 2005), to look for a cointegration relationship between oil and natural gas prices. Using annual data, in a slightly different approach, from the US market between 1960 and 2007, Mohammadi (2009) examines long-term and short-term dynamics between electricity prices and fossil fuel prices (coal, natural gas and crude oil). The author concludes that fuel prices do not affect electricity prices significantly, finding only significant long-term relationships between electricity and coal prices. In a different approach, Bencivenga and Sargenti (2010) studied the level of integration between gas, oil and electricity markets in Europe and in the US in order to capture possible different long-term and short-term dynamics caused by a different level of deregulation existing on each market. The authors use daily price data from 2001 to 2009 to conclude for an erratic relationship in the short run while in the long run an equilibrium may be identified having different features for the European and the US markets.

Gjolberg (2001) explores possible medium and long-term correlation between electricity and fuel oil in Europe. Besides natural gas, crude oil and electricity prices show cointegration, crude oil has been identified has having a leading role between 1995 and 1998, right during the interim period after the UK gas market deregulation in 1995. Chemarin et al. (2008) analyze the role of green certificates over the French electricity production market applying the GARCH bi-assorted time series econometric models showing that both markets are cointegrated. Later, Mohammadi (2009) finds a stable long-term and bi-directional causality between coal and electricity prices, but conclude for an insignificant long-term relation between electricity, crude oil and/or natural gas prices. Moutinho et al. (2011) analyze both long-term and short-term relation between commodity prices (electricity, crude oil, fuel oil, coal and natural gas) using daily spot prices between 2002 and 2005 from the Spanish electricity market. They found that in the long-term relation the prices of fuel and the prices of Brent are tangled, but that Brent prices tend to move in order to reestablish equilibrium. They use time series methodologies (vector autoregressive, VECM and Granger) to also find that the price of electricity is explained by the evolution of the natural gas series.

There are other investigations which try to relate electricity, carbon and fuel sources. Madaleno et al. (2014) analyze the relationship between the returns for carbon, electricity and fossil fuel price (coal, oil and natural gas), focusing on the impacts of emissions trading via a VECM for both German and French markets. Results show that the effect of carbon depends on the energy mix of the country under analysis but that it is not the only factor. The authors state that less carbon coercion takes place in the European energy exchange and innovations in carbon are not strongly reflected in electricity prices. They also evidence that market power affects the correct transfer of prices, thus limiting cost increases. Brooks and West (2013) use the DCC GARCH model to study the integration between coal, natural gas, EUA emissions, and crude oil, fuels which account for approximately 80% of EU27 annual energy production during the period January 22, 2009-July 20, 2012. A strong level of market integration through time was not consistently observed, even when accounting for periods of divergence when market behaviors were distressed by economic shocks and supply disruptions. The results point for important diversification advantages which can be obtained from the European energy portfolio, by finding no evidence for an energy mix. Kirat and Ahamada (2011) model the prices of various electricity contracts in France and Germany finding that electricity producers in both countries were constrained to include the carbon price in their cost functions during the first 2 years of the EU ETS, with German electricity producers more constrained. They also find evidence of fuel switching in electricity generation in Germany after the collapse of the carbon market.

For what we have seen, much more needs to be done with respect to the European market, which is betting strongly in energy efficiency and pollution reduction through major directives which have been implemented both nationally and as a group. Moreover, it is noticed from this analysis that different methodologies have been applied, which account only for time series and for a few number of countries. Our work, tries to analyze cointegration relationships among electricity and fossil fuel prices using panel data methods, thus improving the analysis with respect to previous empirical findings. Also we take into account both the industrial and household sectors, two of the most important energy consumers sectors in any country to see if significant differences emerge.

3. DATA AND METHODOLOGY

Data consists of observations of energy commodities prices, specifically electricity prices and fossil fuel prices (coal prices, gas prices and oil prices) in industry and households for 22 European countries (Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom and Switzerland). It employs annual data for prices variables in the time span 1996-2013. The sources of data for price per toe in €05 of electricity in industry and in household, for constant price toe in €05 of natural gas in industry and in household, for constant price toe in €05 of bituminous coal in industry and in household come from the Eurostat and for price per toe in €05 of light fuel oil in industry and in household sector from the BP statistical review of world energy, June 2014. Data for 22 European countries economies reveals series with 17 years (a moderate panel number) of observations and few outliers. It is worth to perform a study of this kind, while noting that the economic regimes shifts could permanently change the nature of the electricity price-fossil fuel prices relationship.

Allowing markets deregulation and integration is to allow the markets to quickly respond to supply and demand conditions. Electricity prices may respond to price changes in their major fuel source markets (Mjelde and Bessler, 2009). These should in turn respond to changes in electricity prices (Asche et al., 2006). We should also expect that fuel source prices are at least weekly integrated due to their nature and use (Bachmeier and Grifin, 2006). So, and as suggested by economic theory and intuition we should find a relationship between input and output prices.

Natural gas is an important source of electricity generation and a higher demand for electricity translates into an increase in the need for natural gas (EIA, 2010). Natural gas is more fuel efficient, provides better operational flexibility, lower emission and capital costs (EIA, 2010). We should bear in mind that the main goal of the EU ETS is to encourage industries bigger emitters to reduce carbon emissions and invest in clean technologies. This implies a real carbon price signal inducing electricity producers to make long run choices to produce electricity with fewer emissions. Similar to the cost of fossil fuels, economic theory also suggests that the carbon price is a marginal cost which should be similarly reflected into electricity prices. Moreover, where industrial tariffs are likely to be cross-subsidized by households' consumers, the deployment of renewables has a greater overall effect in raising household prices relative to the case of no cross-subsidization, and so households bear a larger share of the cost of renewable support schemes in these cases.

Cointegration analysis on the multivariate data set of cross-country panel data is used to capture causalities that may exist between electricity prices and fossil fuel prices like coal, gas and oil prices. By applying panel data estimations, a series of tests have been conducted like panel unit root tests, a panel cointegration test and some dynamic panel causality tests. To allow the characterization of the possible nature of interdependence of the short run movements of cointegrated variables, which in the present setting are electricity, gas, coal and oil, the error correction model (ECM) is a comprehensive linear regression equation.

3.1. Panel Unit Root and Panel Cointegration Tests

We start by using panel unit root tests to verify empirically if the variables used in the present setting are non-stationary. These sorts of tests are usually grouped into two main categories called the first-generation tests, by assuming cross-sectional independence (Maddala and Wu, 1999; Choi, 2001; Levin et al., 2002; Im et al., 2003), and the second generation tests, which assume some form of cross-section dependence (Pesaran, 2007).

Following Levin et al. (2002) proposed panel-based augmented Dickey–Fuller (ADF) test, it is first tested the null hypothesis that all individual series of the panel contain a unit root. This test restricts parameters by keeping them identical across sectional regions and by assuming the following form, known as the LLC test:

$$\Delta y_{it} = c_i + \rho_i \cdot y_{it-1} + \sum_{j=1}^{k} c_j + \rho_i \cdot y_{it-j} + \varepsilon_{it} \quad (1)$$

being $t = 1,2,\ldots T$ the time periods and $i = 1,2,\ldots,N$ the respective panel members. This test assumes the null hypothesis $\rho_i = \rho = 0$ for all i and the alternative $\rho_1 = \rho_2 = \ldots = \rho < 0$ also for all i, being the test based over the statistic $t_\rho = \hat{\rho} / s.e.(\hat{\rho})$. A problem of this test is that ρ is restricted by being kept identical across regions under both the null and alternative hypotheses. To further highlight non-stationary tests results besides the LLC test, the current work also employs the Hadri test (Hadri, 2000) which assumes a common unit root and both the IPS and the ADF-Fisher tests which assume individual unit root processes across the cross-sections.

With respect to panel cointegration tests we follow Pedroni (2001; 2004) applying his proposed within-groups statistics. The statistics based on the homogeneous alternative hypothesis consists on estimates of pooled type. His between-groups estimators considers the heterogeneous alternative hypothesis whose test statistics are formed by means of the estimated individual values for each panel unit *i*.

3.2. Estimation of the Cointegration Vector

After showing the variables non-stationary and the common presence of cointegration we may infer which long run equilibrium deviations occur and influence the short run variables dynamics in the equation. This may be done through an ECM model represented by equation (2):

$$\Delta y_{it} = \phi_i (y_{i,t-1} - \theta_i^{'} \cdot X_{it}) + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \cdot \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}^{'*} \cdot \Delta X_{i,t-j} + \mu_i + \varepsilon_{it} \quad (2)$$

Where $\phi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij})$, $\theta_i = \sum_{j=0}^{q} \delta_{ij} / (1 - \sum_k \lambda_{ik})$, $\lambda_{ij}^{*} = -\sum_{m=j+1}^{p} \lambda_{im}$, being $j = 1,2,\ldots p-1$ and $\delta_{ij}^{'*} = -\sum_{m=j+1}^{q} \delta_{im}$, with $j = 1,2,\ldots q-1$.

We play particular attention to the parameters ϕ_i and θ_i, respectively, the speed of adjustment from the error correction term and the vector of parameter of long run equilibrium relationship. It should initially be expected that the parameter ϕ_i would be different from zero and significantly negative under the assumption that the variables return to their long run equilibrium.

With respect to ECM models and to estimate the cointegration vector we use here the methods PMG, DFE, FMOLS and DOLS. We need to take into account the Pedroni (2001) recommendations that FMOLS and DOLS estimators are advantageous in their group-means versions. This is due to the greater flexibility under the presence of heterogeneity in the cointegration vectors and to lower size distortion than the estimators within groups.

In a last stage of this work we also introduce into the analysis the carbon allowances to infer about its impact over electricity and fuel sources since its introduction in 2005 in the EU. We haven't use price data for this series since the beginning of our estimations because the time span starts in 1996 but allowances markets have only became available in 2005.

4. EMPIRICAL RESULTS AND DISCUSSION

This section presents the results obtained for the panel unit root tests, the panel cointegration results and the ECM results attained. Table 1 reports unit root tests for the relationships between electricity prices and fossil fuel prices for industry (Model 1) and households (Model 2) for the panel group which includes 22 countries. All test regressions contain an intercept and a time trend.

From Table 1 we may see that the LLC test rejects the presence of unit root under significantly weaker evidence for all variables. The Hadri test has a different (stationary) null hypothesis and provides strong evidence that (at least) all panels have a unit root. The IPS test shows results similar to the ADF-Fischer test. These points for the result that we may reject the presence of unit root in electricity and fossil fuel prices.

In general, we conclude that the assumption of the non-stationary of the series is legitimate, indicating the possibility of long-term relationships between the variables. Furthermore, the results are valid simultaneously for both industry and household sectors. Considering the cases in which the null hypothesis was rejected, it is possible to include such variables in the cointegration study in the following situations: firstly, assuming that they are first-order integrated and, secondly, when the panel test does not show such results due to the high probability of the presence of cross-section correlation.

Going further, even if the series are non-stationary, the relationship between variables may be spurious. For this, it is necessary to perform the panel cointegration tests to make sure that there is indeed a long-term relationship. In Table 2, as far as the Pedroni's and Kao's test statistics are concerned, the results do provide strong support for the presence of cointegration (Engle and Granger, 1987; Kao and Chiang, 2000).

Overall, the results of all three equations suggest that all variables (electricity price, coal price, oil price, gas price) in industry and households are cointegrated, which means that we have uncovered meaningful long run relationships and this highlights the importance of the analysis being performed in the current setting, as we have also emphasized at the beginning.

Finally, ECM models results are to be performed, presented and discussed. For this, the long and short run estimates, based on different estimation for European industry and households, are reported in each column of Tables 3 and 4, respectively. The first and second columns of each Tables 3 and 4 report the results of FMOLS and DOLS techniques, and provide information on the long run relationship between electricity prices (dependent variable) and fossil fuel prices (independent variables). Included are the cross-effects in fossil prices before and after the 1996-2004 period and accounting also for the 2005-2013 periods, where it was included in the analysis the absence and presence of the CO_2 prices effect respectively. For this propose we included the dummy variable CO_2 allowances prices from 2005 onwards.

Results from Table 3 account for all 22 European countries and for the industry sector prices. Panel results for fossil fuel prices in columns (1) and (2) show that one unit increase in oil and gas prices increases electricity prices positively while coal prices increase negatively electricity prices for the entire period analyzed (1996-2013). All these results are statistically significant, except that of oil in DOLS. Moreover, we should also expect a positive impact of coal prices over electricity prices, but the negative price obtained may be an effect of the renewables substitution policies effect.

The negative sign is not always presented in all estimates and also not always significant when we account for the dummy carbon allowances (line 4). In addition to the rise in oil and gas production, consuming countries have sought to diversify their energy mix – i.e. reduce the share of fossil fuels and increase the share of alternative energy, particularly renewable sources. These efforts are driven mainly by concerns over energy security and climate change. According to the EIA (2010), the EU has strong

Table 1: Results of panel unit root tests

	Test assuming a common unit root process		Tests assuming individual unit root process	
Series name	**LLC t*-statistics**	**Hadri Z-statistics**	**IPS W-t-bar statistics**	**ADF-Fisher χ^2**
Model 1	**H_0: Unit root**	**H_0: No unit root**	**H_0: Unit root**	**H_0: Unit root**
Level				
Electricity price	−3.7154*** (0.000)	7.4738*** (0.000)	−0.5591 (0.2881)	2.2393** (0.012)
Coal price	−4.2421*** (0.000)	7.4164*** (0.000)	−2.1906** (0.014)	1.6572* (0.048)
Oil price	−10.7105*** (0000)	2.7574*** (0.002)	−8.9637*** (0.000)	4.9606*** (0.000)
Gas price	−5.5870*** (0.000)	5.0677*** (0.000)	−3.2873*** (0.000)	0.0557 (0477)
Model 2	**H_0: Unit root**	**H_0: No unit root**	**H_0: Unit root**	**H_0: Unit root**
Level				
Electricity price	−1.8494** [0.032]	10.159*** [0.000]	10.726*** [0.000]	1.9874** [0.023]
Coal price	−5.6017*** [0.000]	7.6476*** [0.000]	7.0820*** [0.000]	−0.5093 [0.694]
Oil price	−8.3936*** [0.000]	11.779*** [0.000]	3.0427*** [0.001]	3.3599*** [0.000]
Gas price	−3.3129*** [0.000]	10.295*** [0.000]	8.6962*** [0.000]	−1.1528 [0.875]

Table 1 presents unit root test results for the relationship between electricity price and fossil fuel prices, assuming a common unit root process (columns[2] and [3]) and assuming individual unit root processes (columns[4] and [5]), for industry (Model 1) and households (Model 2) for 22 countries between 1996 and 2013 and on the basis of annual observations. *,** and *** represent significance at the 10%, 5% and 1% levels respectively, ADF: Augmented Dickey–Fuller

Table 2: Results of panel cointegration tests

Model 1	**Kao**			**Pedroni**	
Panel ADF-statistic	−4.1990*** (0.000)	Panel v-statistic	−0.44176 (0.664)	Group rho-statistic	3.21896 (0.999)
		Panel rho-statistic	1.3134 (0.887)	Group PP-statistic	−1.8955** (0.029)
		Panel PP-statistic	−1.5161** (0.050)	Group ADF-statistic	−2.9750*** (0.001)
		Panel ADF-statistic	−2.6488*** (0.000)		
Model 2	**Kao**			**Pedroni**	
Panel ADF-statistic	−3.5206*** (0.000)	Panel v-statistic	0.2499 (0.547)	Group rho-statistic	3.3951 (0.999)
		Panel rho-statistic	1.6884 (0.922)	Group PP-statistic	−0.2070 (0418)
		Panel PP-statistic	−1.1147* (0.101)	Group ADF-statistic	−2.183** (0.014)
		Panel ADF-statistic	−2.271*** (0.006)		

Pedroni's and Kao's test statistics for the presence of cointegration, for industry (model 1) and households (model 2) for 22 countries between 1996 and 2013 and on the basis of annual observations. *.** and *** represent significance at the 10%, 5% and 1% levels respectively. ADF: Augmented Dickey–Fuller

Table 3: Panel cointegration estimation results: Industry

Model 1	**(1) FMOLS**	**(2) DOLS**	**(3) PMG**	**(4) DFE**
Dependent variable:	Ln electricity price	Ln electricity price	ΔLn electricity price	ΔLn electricity price
Convergent coefficients			−0.130739*** (0.000)	−0.2003*** (0.000)
Long-run coefficients				
Ln coal price	−0.02405* (0.464)	0.1254** (0.041)	0.51311*** (0.000)	0.07261 (0.627)
Ln oil price	0.17131*** (0.000)	0.0131 (0.729)	−0.28546** (0.047)	0.0343 (0.830)
Ln gas price	0.3973*** (0.000)	0.3216*** (0.000)	0.71959*** (0.000)	0.4158*** (0.009)
D2005* Ln coal price	−0.05250 (0198)	−0.0867*** (0.002)	−0.051362 (0.382)	−0.0167 (0.879)
D2005* Ln oil price	0.1749*** (0.000)	0.1106*** (0.003)	−0.23026 (0.167)	−0.2958* (0.071)
D2005 Ln*gas price	−0.0796*** (0.000)	−0.0230 (0.565)	0.32436* (0.082)	0.3469* (0.071)
Short-run coefficients				
ΔLn coal price			0.07654 (0.475)	0.02632 (0.527)
ΔLn oil price			−0.04084 (0.507)	−0.0597* (0.077)
ΔLn gas price			−0.01272 (0.875)	0.04308 (0.248)
Δ D2005* Ln coal price			−0.15963 (0.192)	−0.03185 (0.384)
Δ D2005* Ln oil price			−0.02937 (0.712)	0.0193 (0.628)
Δ D2005* Ln gas price			0.15228* (0.101)	0.00718 (0.868)
Hausman test (χ^2)			0.74 (0.941)	
R-square (r^2)	0.579	0.895		
Number of countries	22	22	22	22
Number of observations	396	396	396	396

ECM models for the industry sector in Europe. Columns (1) and (2) provide information about the long run relationship between electricity prices (dependent variable) and fossil fuel prices (independent variables), including the cross-effects in fossil prices before and after 1996-2004 and including the absence and presence of CO2 prices (2005-2013 dummy). PMG and DFE estimators are presented in columns (3) and (4), respectively. Ln refers to log prices and ΔLn to log price changes. *, ** and *** represent significance at the 10%, 5% and 1% levels respectively. PMG: Pool mean group, FMOLS: Fully modified ordinary least squares, DOLS: Dynamic ordinary least squares, DFE: Dynamic fixed effects, ECM: Error correction model

position in solar PV and wind, as it produced in 2010 around 70% of world's electricity generated from solar PV and 44% of global wind production. These developments provide simultaneously opportunities and risks for the EU renewable sector and the whole economy, related to trade flows in renewable energy equipment, maintaining the leading position in green technologies and possible

Table 4: Panel cointegration estimation results: Households

Model 2	(1) FMOLS	(2) DOLS	(3) PMG	(4) DFE
Dependent variable	Ln electricity price	Ln electricity price	ΔLn electricity price	ΔLn electricity price
Convergent coefficients			−0.25248*** (0.000)	−0.20799*** (0.000)
Long-run coefficients				
Ln coal price	0.11538*** (0.000)	0.1289*** (0.008)	0.14703* (0.066)	0.11567 (0.455)
Ln oil price	−0.1935*** (0.000)	−0.0578 (0.189)	0.01118 (0.800)	0.20863** (0.044)
Ln gas price	0.2701*** (0.000)	0.2206*** (0.000)	0.31086*** (0.000)	0.3487*** (0.001)
D2005*Ln coal price	0.0959** (0.046)	0.00138 (0.967)	−0.01670*** (0.000)	0.0768 (0.309)
D2005* Ln oil price	0.0089 (0.784)	−0.0962* (0.091))	0.24331*** (0.000)	−0.13290 (0.231)
D2005*Ln gas price	−0.0157 (0.634)	0.1187** (0.050)	−0.06046* (0.101)	0.04448 (0.680)
Short-run coefficients				
ΔLn coal price			0.07095 (0.416)	0.06147 (0.245)
ΔLn oil price			−0.05484 (0.331)	−0.05582** (0.018)
ΔLn gas price			0.2138*** (0.002)	0.1138*** (0.003)
Δ D2005*Ln coal price			0.19904** (0.016)	−0.00132 (0.955)
Δ D2005*Ln oil price			0.03074 (0.572)	0.034121 (0.184)
Δ D2005*Ln gas price			−0.2162*** (0.006)	−0.03257* (0.321)
Hausman test (χ^2)			4.21 (0.651)	
R-square (r^2)	0.569	0.751		
Number of countries	22	22	22	22
Number of observations	396	396	396	396

ECM models for the household sector in Europe. Columns (1) and (2) provide information about the long run relationship between electricity prices (dependent variable) and fossil fuel prices (independent variables), including the cross-effects in fossil prices before and after 1996-2004 and including the absence and presence of CO_2 prices (2005-2013 dummy). PMG and DFE estimators are presented in columns (3) and (4), respectively. Ln refers to log prices and ΔLn to log price changes. *,** and *** represent significance at the 10%, 5% and 1% levels respectively. PMG: Pool mean group, FMOLS: Fully modified ordinary least squares, DOLS: Dynamic ordinary least squares, DFE: Dynamic fixed effects, ECM: Error correction model

expansion to non EU markets, as well as possibilities to avoid some imported fuel cost like that of oil, being the majority of EU countries oil importers.

For the complete period, long run results show estimates of −0.024 and 0.397 for the elasticity of the electricity price with respect to coal and gas prices. Accounting for the effect of CO_2 prices (2005-2013), the elasticity of the electricity price for coal and gas increase and decreased 0.028 and 0.32 units, respectively.

The PMG estimation shows different results to those of FMOLS. The speed of adjustment is as expected negative (magnitude −0.130) for the entire period. When comparing the Hausman tests using PMG and DFE estimators, it is possible to conclude that the PMG estimator is preferred to the DFE estimator for both regulatory periods.

Presented results also show that the PMG long run estimates of the coal and gas prices have a positive impact over the elasticity of electricity prices in Europe considering the industry sector for all period. The differential increase in the elasticity of electricity prices with respect to gas price for the 2005-2013 periods is lower than the same impact for the previous period (1996-2004). Except for gas and FMOLS estimates, coefficients for fuel prices like coal and oil are negative in the 2005-2013 periods. The dummy accounts for the cross effect of allowances introduction and fuel prices over electricity prices. Moreover, the coefficient magnitude with respect to gas decreases when we turn from the overall period to the shorter period except in DFE estimates. Both the decrease and the negative sign may be an indicator of the stronger effect of the energy policy pursued in Europe. Trying to fight greenhouse gas emissions and the European bet in increased share of renewables could explain these significant results. Furthermore, we should bear in mind that among the three studied fuel sources (coil, oil and gas), natural gas is more fuel efficient, provides better operational flexibility and also lower emissions (EIA, 2010).

On the other hand, the PMG and DFE estimates show no significant coefficients estimated results for the short run period. The estimates of speed of adjustment for the PMG, and DFE are all negative for all period analyzed.

Table 4 presents the results for the model for European Households Electricity market specifying the relationship between electricity prices as the dependent variable, when coal, oil and gas prices are the independent variable. The goal is to see if coefficient signs change depending over the sector and also to see if fuel prices exert the same effect over electricity when accounting for industry and households separately. The first thing to notice is the significance increase in the household sector with respect to short run coefficients. Once again we consider two different periods: the entire analysis period (1996-2013) and that considering the introduction of allowances markets in Europe (2005-2013).

Results show that the FMOLS long run estimates of the oil price has a negative impact on the elasticity of electricity prices in the European electricity households market. In terms of electricity supply to households, may be the share of coal in domestic prices is still high and the non-complete openness of the market could explain this result. Despite this, coal has been gradually substituted by other energy sources in order to accomplish the necessary greenhouse gas reduction imposed by the EU directives (ECB, 2010). However, results are more consistent with the economic rational that fuel price increases have a positive influence over electricity prices, being the oil coefficient in households a surprise. When accounting for PMG and DFE results, this evidence gets stronger. But, this result is only consistent for the entire period of analysis, being mixed for the short run. In terms of short run coefficients some coefficients reveal significance in the entire period of analysis which allows us by comparison with the industry sector state that household electricity prices are more sensitive in the short run to fuel price increases. Once again, curiously, oil prices still have a negative sign in the short run which doesn't disappears completely once we take into account the effect of the allowances market for both the short and long run cointegration analysis considered.

Also, by opposition to what happens in the industry sector, when we account for allowances dummy the differential increase in the elasticity of the electricity price with respect to oil is lower in both FMOLS and DOLS models, while this differential seems to increase in the electricity price elasticity for coal and gas prices from the entire period to the shorter 2005-2013 period. The PMG estimates show significant coefficients estimated results for the short run period, being once again the estimates of speed of adjustment for the PMG and DFE all negative for the overall period analyzed. The estimates of speed of adjustment indicate no significant difference in the long run dynamics (−0.252 for PMG and −0.207 for DFE). This implies that in all models, for the 1996-2013 period analyzed all fossil fuels prices do not return immediately to their equilibrium after a shock pushes them away from the steady state. As the error correction term is statistically significant it provides further evidence of the existence of a long run relationship.

When comparing PMG and DFE estimators, the Hausman test result is 4.21 respectively; then, it is possible to conclude that under the null hypothesis the PMG estimator is preferred.

The short run coefficients estimates have mixed signs within analysis periods, and the lack of statistical significance for the shorter period induce us to state that fossil fuel prices variables effects over the elasticity of electricity prices do not have a significant relation to explain the elasticity of electricity prices in the European households electricity prices analyzed in the short run, still having more than when we consider the industrial sector.

5. CONCLUSIONS AND POLICY IMPLICATIONS

This work adds to the preexisting literature by analyzing the electricity-fuel nexus for 22 European countries, employing panel data methodologies and taking into account the cross-section dependence between countries. This approach allows showing whether the variables exhibit some common dynamics among the countries using the FMOLS and DOLS models. It is also used heterogeneous panel cointegration tests robust to cross section dependence and a PMG and DFE estimators to distinguish between short run and long run relationships and especially between short and long run causalities. We also account for different sectors (industry and households) to find surprisingly differences in both short and long run cointegration among electricity and fuel sources (oil, coal and gas) as well as for different time periods (1996-2013 and 2005-2013), the last to consider allowances introduction through a dummy variable) using annual data.

The main findings may be summarized as follows. First, we find that the series are dependent across countries. Secondly, we show that electricity and fuel prices are integrated of order one and highlight a long run equilibrium relationship between variables. Third, we find that besides the long run relationship between electricity and fuel sources in the industrial sector, for the household sector there is a simultaneous short and long run one. Fourth, in absolute terms all elasticity coefficients are positive, but oil and coal prices show a negative and significant impact over electricity prices in the household and industry sector, respectively. Finally, most fuel price impacts lose their significance over electricity prices when we account for the allowances period in the household sector.

The cointegration tests allow assessing whether there is a long run equilibrium relationship, but they do not provide parameter estimate either for the long run or for the short run. To estimate the cointegration vector, the between dimension FMLOS and DOLS estimators have been used. The rationale behind this estimator is to correct for endogeneity bias and serial correlation and thereby allow for standard inference.

Some of our findings may be explained by the rational of contracts performed for industry and households. While industries may have long run contracts with suppliers of energy, households do not have this possibility up to the moment in the majority of EU countries. That is to say, that besides the recommendations for the electricity market liberalization throughout Europe few of the countries included into the present analysis has already reached an adequate opening level in this sense. We should also be aware that households are almost inelastic with respect to electricity price fixation because we still have a strongly regulated market. So, the relation between electricity and fuel sources is translated into a relationship of cause effect with no direct causality nexus, being this stronger for the industry sector.

ECB (2010) and Dee (2011) state that the higher the competition among suppliers, the lower the expected end user prices, because it puts downward pressure on profit margins and provides an incentive to reduce costs and achieve higher levels of efficiency. This creates distortions and negates the effectiveness of market opening in delivering competitive price signals, thus turning harder the implementation of unregulated prices, a part of Member States' structural reforms.

We only know that we are dealing with annual prices of companies within the industry sector. But, many of these may be electricity producers and thus able to explain many of the mixed results evidence here presented through cointegration panel models estimates. In the industry sector we have more the fixing of long run contracts (for example futures) being the spot price used as a market reference of these long run contracts solely in the majority of the situations. As such, we are able to explain the lower sensibility of electricity prices to fuel price changes obtained for the short run. When prices move in the day-to-day life and given that we still have regulated and non-completely competitive electricity markets which are now moving towards deregulation, there is only an annual price revision in these contracts which are year by year reflected in household final paid prices for electricity. So, there exists more rationale within this sector to see stronger short run influences with statistical significant as that presented in the current setting. In industries what we have is that short run price changes influence the long run contract values more than the short run one's. As such, we find enough evidence to justify the speed of electricity markets liberalization in Europe, thus reinforcing the need for a quicker adjustment in the countries which are only now starting this process if the goal is in fact to bet in the renewables market and create a common competitve electricity market with all expected price interactions and markets interconnections.

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