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Examining the long term relationships between energy commodities prices and carbon prices on electricity prices using Markov Switching Regression

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Abstract

The present work aims to quantitatively measure the relationships between the price of energy commodities, coal, gas natural, fuel oil, carbon prices and the price of wholesale electricity in the Iberian Electricity Market, using 2018 daily data. To examine this relationship, we considered both techniques, Markov-Switching Dynamic Regression and Markov-Switching Autoregressive Regression, and proposed two equations with electricity price and coal price as dependent variables. According to the parameters estimated in the model, coal and gas affect the cost of electricity moderately at times in the day that are highly recessive. During the 2018 daily periods analysed, the relative changes in gas and coal prices led to a loss of competitiveness of natural gas, increased by the moderate evolution of carbon prices, and therefore the cost of coal fell sharply in the recent past. The evolution of both time-varying transition probabilities and energy commodities prices variables is informative. The transition probabilities of staying in the same state change throughout our sample of energy commodities and wholesale electricity prices. © 2022 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

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1. Introduction

The wholesale Iberian electricity market includes transactions arising from market generators' participation in the sessions, where the daily market is the platform in which most transactions occur. Moreover, several technologies with different cost structures coexist side by side: technologies with low variable costs operating almost continuously; and technologies with higher variable costs generating electricity discontinuously and depending on exogenous flows such as the ones from water rivers, solar and wind intensity. The relationships between carbon and the future energy market were studied in France, Germany, Nordic countries and the UK by [1] in Phase-II of the

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EU ETS-European Union Emission Trading Scheme - (2008–2012). The results show a two-way causal relationship between future electricity prices and carbon for the Nordic countries and the European Energy Exchange. There is evidence of a one-way causality for the French market starting from electricity to carbon prices, while the opposite ratio has been noted in the UK. Having this information, the authors concluded that electricity generators in the Nordic countries, Germany and the UK, allocate the costs of carbon emissions to the price of electricity, more than proportional to the increase in carbon-derived costs [1]. In addition, the authors documented that coal was the commodity that had the greatest influence on the price of electricity in the European continent in the period studied [1]. The research proposed by [2] is similar to [1], but [2] investigated the European market during phases-I, -II and -III, respectively, for the years 2005–2007, 2008–2012, 2013–2016. The Granger causality approach points to a two-way relationship during phase-I and that in phase-II, it becomes unidirectional, starting from electricity to carbon [2]. With the results obtained, the authors inferred there would be a weakening of the influence of the carbon market in the electricity market [2]. According to [3], in the period 2005–2010, the price on EU ETS of energy depends on the fundamental energy sources, mainly natural gas and coal, there is a one-way causality from the fundamental energy sources for EUA (European Union Emission Allowance) prices [3]. In reverse, [4] found a two-way causality between the future price of electricity and the carbon market for the period between January 2008 and December 2012, phase-I and -II of ETS [4]. [5] concludes, in phase-II and -III that the future carbon market is linked to movements in the future market of electricity, natural gas and coal [5]. [6] investigated this transfer in the German and UK economies and concluded that transfers are not constant and that the final electricity price is determined by marginal production [6].

This research aims at examining the relationships between the prices of spot electricity, fossil fuels and carbon emissions prices, important for the implementation of an eco-energy-oriented policy that addresses environmental implications. So, for this aim, we employ the Markov-Switching (MS) regression models developed by [7]. A jump in electricity prices can then be considered as a change to another regime, for example [8,9]. For the remaining sample, electricity prices in Iberian Market were characterized at a high state. To study whether the energy commodities prices and CO₂ prices contribute to understanding movements in electricity prices, we: (i) analyse time-varying transition probabilities parameters in terms of their signs and significance; and (ii) question whether changes in two different regimes seem to be influenced by changes in series prices variables. Although there is evidence showing a long run nonlinear relationship between energy commodities prices and wholesale electricity prices, the short-term nonlinear pricing effects of electricity prices have not been analysed yet for Iberian Market during the 2018 year.

2. Methodology and data

Unlike revisited literature typically based on univariate models, we employ multivariate models that appropriately allow us to capture the possible endogenous relations, including the short-term dynamics and long-term adjustments between the CO₂ price, spot electricity and oil prices, natural gas and fuel oil prices. This approach also permits us to study the effects of innovations in the prices of these energy commodities on the cost of CO₂ in terms of persistence and magnitude. Therefore, it seems important to allow for interactions of series prices of commodities, electricity price and CO₂ price. In our methodology to validate our proposed model, we used MSR models developed by [7] and following the study developed by [10]. This estimation involves multiple equations to characterize the time behaviour of a series of prices in different regimes, and this model captures dynamic patterns. The MS model can be employed to model time series where the variables occasional changes in time. The model considers that a conditional distribution of a time series sample is subject to an inherent latent state or regime. The MS model can assume a finite number of values and change over time as a Markov chain [8]. Because of this characteristic, the MS is widely used in financial and economic works since the financial and economics phenomenon can be classified easily into those regimes [8]. According to [9], the MS can, probabilistically and visually, analyse a business cycle. The MS model has two main categories: the MS Dynamic Regression (MS-DR) and the MS Autoregressive (MS-AR).

The MS-DR is represented by Eq. (1), where the process of state changes is set by the Markov stochastic process at every point [9].

$$y_t - \mu_{s_t} = y_{t-1} - \mu_{s_{t-1}} + z.\text{epsiv};_t, z.\text{epsiv};_t \sim i.i.d.N(\mu_{s_t}, \sigma_{s_t}^2) \quad (1)$$

in which, s_t is a latent variable at the point of time t ; y_t is a state time series information at point t , and also represents the changes; μ_{s_t} is a tendency term and $\sigma^2_{s_t}$ is the distribution term [9]. According to [8], the inherent regime changes thought the time as a first-order Markov chain, with the transition probabilities as follow:

$$P \{s_t = j | s_{t-1} = i, s_{t-2} = k, \dots\} = P \{s_t = j | s_{t-1} = i\} = p_{ij} \tag{2}$$

s_t is supposed to follow an ergodic M-State Markov process, with an indivisible transition matrix [11], where $p_{11} + p_{MM} = 1$. The probability vector for the next stage (s_{t+1}) is the product from the transition matrix and the conditional probability vector ate the current stage (s_t) [9].

The MS-AR is recommended in scenarios where the variables under estimation change their nature during time [10]. The autoregressive vectors (VAR) will be regime-dependent in this model [10]. The time-series vector of conditional probability, y_t , can be represented as follow (3), if the regimes respect this condition $s_t \in \{1, 2, 3, \dots, S\}$ [10].

$$P (y_t | Y_{t-1}, s_t) = \begin{cases} f (y_t | Y_{t-1}, \theta_1) & \text{if } s_t = 1 \\ \vdots \\ f (y_t | Y_{t-1}, \theta_s) & \text{if } s_t = S \end{cases} \tag{3}$$

where θ indicates the VAR model parameters and Y_{t-1} represent all the data from the starting point of the sample until the y_{t-1} [10]. Having exposed this, the y_t will be generated by the following VAR process:

$$y_t = \mu (s_t) + \sum_0^q A_i (s_t) y_{t-1} + \mu_t, \\ \mu_t \sim NID(0, \sum (s_t)) \tag{4}$$

where μ represents the intercept or mean for each regime, A_i the matrix and, and for the last, \sum is the variance of the residuals for each regime. As in the MS-DR, the MS-AR model approach s_t is determined through a Markov chain and a $\Pr\{s_t | s_{t-1}\}_{i=1}^\infty, \{y_{t-1}\}_{i=1}^\infty = \Pr\{s_t | s_{t-1}; \rho\}$, where ρ is the probabilities parameters [10]. Like the MS-DR, there is a probability matrix, defined by the following equation: $P_{ij} = P \{s_{t-j} | s_{t-1} = i, s_{t-2} = l, \dots\} = \Pr\{s_t = j | s_{t-1} = i\}$. Where $\sum_j^s = 1$ and $P_{ij} = 1$ [10].

The estimated model coefficients and the calculated probability matrix make it possible to estimate the probability of being in j state in each period, known as the smoothed probabilities [10]. Additionally, it is also possible to calculate the probability of being in j state only with the date information. This is known as filtered probabilities [10].

In this empirical study, we included the price of electricity as the dependent variable; and four explanatory variables: cost of coal; cost of natural gas; cost of fuel oil, and the CO2 emissions price. The coal price is the API2, the natural gas is the TTF, the Fuel is the CIF NWE 1% S, and CO2 emission allowances is the BLUENEXT emissions market. The time series of these prices relate to daily data for the 2018 period, and the dataset includes 366 observations. All series of dependent and explanatory variables are transformed to natural logarithms.

3. Empirical results

The results of MS-DR, in Table 1, Model 1, first equation, show for coal price, fuel oil and carbon price a significant impact at 1% level on electricity price, while in second equation the price of fuel oil and carbon price presents a significantly effect on the price of coal commodity. The equations estimated in model 2 can be used to examine, at first differences, the effects of coal prices, natural gas, fuel oil and carbon prices on electricity prices, in Eqs. (1) and (2), respectively. The dependent variable in both equations is the electricity price, i.e., D. Electricity price and D.Coal price, respectively. The first difference values of all variables are also shown in Table 1.

The estimated coefficients of coal price natural gas price are significant impact t 1% level only in the first regime, while fuel oil price and carbon price are significant in the second regime. In the second equation, the first difference of coal price is the dependent variable, the coefficients of the fuel oil price present significantly effect on coal price in the first and second regime, while carbon price has a significant effect on coal price at the 5% level only in the first regime.

Based on the transition probabilities, in Table 1 model 1, and Electricity price as a dependent variable, the probability of changing between regime one (two) and the second (first) regime is 0.9936 and 0.70420, and thus,

Table 1. Results for the Markov-Switching Dynamic Regression (MS-DR).

Model 1	Elect. Price	Coal price	Model 2	D. Elect. Price	D. Coal price
Electricity_Price (−1)	0.4772***		Electricity_Price (−1)	−0.58941***	
Coal_Price (−1)		0.94389***	Coal_Price (−1)		−0.4892***
Regime 1			Regime 1		
Coal_Price (−1)	0.3086***		Coal_Price (−1)	0.55747***	
Electricity_Price (−1)		−0.00815	Electricity_Price (−1)		−0.008402*
Gas-Nat_Price (−1)	0.03512	0.000773	Gas-Nat_Price (−1)	0.15283***	−0.006903
Fuel-Oil_Price (−1)	−0.04462***	−0.04242***	Fuel-Oil_Price (−1)	0.013628	−0.036373**
Carbon_Price (−1)	0.16602***	0.017624**	Carbon_Price (−1)	0.03789	0.015509***
Constant	2.822723***	0.45408***	Constant	−0.69977**	
Regime 2			Regime 2		
Coal_Price (−1)	3.0804		Coal_Price (−1)	14.8568	
Electricity_Price (−1)		0.000526	Electricity_Price (−1)		0.000531
Gas-Nat_Price (−1)	−0.947339	0.01897**	Gas-Nat_Price (−1)	−11.22477	0.00988
Fuel-Oil_Price (−1)	−0.84202	0.02526***	Fuel-Oil_Price (−1)	−14.3474***	0.021325**
Carbon_Price (−1)	0.09803	−0.004405	Carbon_Price (−1)	−5.89336***	−0.001693
Constant	−5.2236	0.05021	Constant	68.9289	0.06282*
<i>Sigma</i>	0.12582	0.008588	<i>Sigma</i>	0.109694	0.0086097
p11	0.99368	0.70420	p11	0.99445	0.69344
p21	1	0.055819	p21	1	0.06093

Notes: All series of variables were transformed to natural logarithms. p11 and p21 denote the probabilities of changing from a recent state to the current state, at states 1 and 2, respectively.

*Denotes 10% levels of statistical significance, respectively.

**Denotes 5% levels of statistical significance, respectively.

***Denotes 1% levels of statistical significance, respectively.

the probability of keeping in regime one (two) in the following period is 1 and 0.0558 in Eqs. (1) and (2) respectively, and both regimes are persistent. On the other hand, in model 2, the probability of changing from regime one (two) to the second (first) regime is 0.9944 and 0.69344, and thus, the probability of keeping in regime one (two) in the following period is 1 and 0.0609 in Eqs. (1) and (2) respectively, and both two regimes are persistent; i.e., p11 and p22 denote probabilities of remaining in the highest regime (state 1) and the probability of remaining in the lowest regime (state 2), respectively. We also document that those changes in the probabilities of remaining at high electricity prices and coal prices regimes (Eqs. (1) and (2)) seem to be started by movements of these dependent variables.

The results showed in Table 2 for the MS-AR, in model 3, show that three regimes were identified: low mean and high precision—regime 1—shows significant evidence at 1% level in Eqs. (1) and (2), while, regime of low mean and medium precision—regime 2—shows statistical evidence at 5% only for Eq. (2); finally, regime of high mean and low precision—regime 3—shows significantly evidence at 1% level in Eqs. (1) and (2) respectively.

In both model 3 and model 4, satisfactory results were obtained using both the two Markov Switching Autoregressive Models considered. For the rest of the sample, Electricity prices were characterized as a high state. Accordingly, the parameters estimated in our econometric approach suggest that during the days of expansions states, coal and gas shocks have positive effects that last a limited period of days. During highly recessionary daily states, coal and gas prices only moderately affect the electricity price system. Moreover, our results document that mitigating nonlinear effects may hide the true effects of coal prices, natural gas, fuel oil and carbon on wholesale electricity prices.

4. Conclusion

This research aims to analyse and evaluate quantitatively the relationship between quantities offers by technologies hydraulic, thermal and special regime with Renewables sources in MIBEL during all hourly days of 2018. The empirical examination used Markov – Switching methods to estimate the relationship between the series of

Table 2. Results for the Markov-Switching Autoregressive (MS-AR).

Model 3	D. Elect. Price	D. Coal price	Model 4	D. Elect. Price	D. Coal price
AR (−1)	−0.45308***	0.576213***	AR (−1)	0.072365	0.283298***
D.Coal_Price	−0.054602		D.Coal_Price	−0.72246	
D. Electricity_Price	0.009122	0.0004425	D. Electricity_Price		−0.00107
D.Gas-Nat_Price	0.707066*	0.028309***	D.Gas Nat._Price	−0.09421	0.012243*
D.Fuel-Oil_Price	−0.062134	0.201603***	D.Fuel-Oil_Price	0.203254	0.17255***
D. Carbon_Price	−0.45308***	−0.013307	D. Carbon_Price	0.26512	0.007489
			Coal_Price (−1)	0.651519***	−0.036668**
			Electricity_Price (−1)	−0.38613***	−0.001697
			Gas-Nat_Price (−1)	0.04031	−0.011275***
			Fuel-Oil_Price (−1)	−0.10945	0.028001**
			Carbon_Price (−1)	0.04877	0.007565**
Constant_Regime1	−0.87482***	−0.0176123***	Constant_Regime1	−0.90178**	−0.0055
Constant_Regime2	0.0053907	0.0017152**	Constant_Regime2	0.164455	0.01834
Constant_Regime3	0.8405122***	0.0193329***			
<i>Sigma</i>	0.117661	0.005387	<i>Sigma</i>	0.16506	0.008952
p11	0.32092	0.413715	p11	0.997239	0.231262
p12	0.118468	0.4762314			
p21	0.011965	0.0991564	p21	0.099999	0.044214
p22	0.988038	0.8219098			
p31	0.169168	0.260889			
P32	0.454762	0.7391108			

Notes: All series of variables were transformed to natural logarithms. p11 and p22 denote the probabilities of changing from a recent state to the current state, at states 1 and 2, respectively.

*Denotes 10% levels of statistical significance, respectively.

**Denotes 5% levels of statistical significance, respectively.

***Denotes 1% levels of statistical significance, respectively.

prices of energy commodities, Carbon emissions prices and the Iberian daily electricity Iberian market price. The research findings will allow us to better understand the nature of the price relationships between spot electricity, oil, gas and fuel and CO₂ prices in the integrated MIBEL market. We extend the model developed by [7] by allowing time varying transition probabilities (TVTP), that probabilities would depend on the dynamics of energy commodities prices and Carbon prices to interpret the probabilities of switching between states of electricity prices. The contribution to the literature of our empirical analysis, specifically the econometric results using, on one hand, a Markov-switching model, was to document a short-run non-linear relationship between electricity price and commodities energy prices. On the other hand, this result helps and informs policymakers about possible price adjustments and the nature of those relationships proposed and estimated.

CRediT authorship contribution statement

Victor Moutinho: Investigation, Formal analysis, Validation, Conceptualization, Supervision, Writing – original draft. **Henrique Oliveira:** Investigation, Writing – review & editing. **Jorge Mota:** Data curation, Formal analysis, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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