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Iberian electricity market spot and futures prices: comovement and lead-lag relationship analysis

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ABSTRACT

Traditionally, the literature on energy prices relied on cointegration methods to study the long-run relationship between spot and futures prices and correlation analysis or causality tests to observe lead-lag relationships between them. In this paper, we examine the comovements and lead-lag relationships within the Iberian electricity market using the continuous wavelet transform which operates in the time-frequency domain. This analysis may allow distinguishing relationships at given frequencies and time horizons. Empirical evidence for the period from July 2007 to February 2017 suggest that correlation between spot and futures markets is positive. Moreover, this result seems to be consistent across all maturities.

Keywords:

Electricity Markets;
MIBEL;
Continuous Wavelet Transform;

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1. Introduction

The European aim of creating a competitive and integrated market for electricity lead to changes from the purely national energy models to the emergence of the concept of regional markets [1]. Under this principle, the Iberian Electricity Market (Mibel) was created in 2004. It was established a common market for electricity in the Iberian region comprising two pillars: a spot market and a futures market. The first is based in Spain and managed by Omel, where electricity is traded and physical delivery takes place in the following day. The former market is based in Portugal and managed by Omip, where derivatives contracts (futures, options and swaps) are traded with electricity produced in both countries as the underlying asset.

The development of a common market for electricity may allow consumers in both countries to access electricity in equivalent conditions, potentially benefiting from a higher degree of competition from power generators/suppliers. The advantages on the creation of MIBEL may stem not only from the benefits arising from increased market competition between power generators, but also, from an increased transparency in the price formation system along with the creation of a futures market for electricity trading. In fact, it is well documented that the creation of futures markets for commodities trading contributes to increase the effciency of the price formation mechanism. Companies with no direct interest in the underlying physical market (such as investment banks, hedge funds, pension funds, etc.) may behave as market participants, providing significant market liquidity and increasing the speed of incorporation of new information into prices. Furthermore, futures markets introduce financial instruments that allow physical market participants (in particular power generators) to hedge price volatility, allowing an improvement in risk management practices [2].

In fact, electricity is a very volatile commodity and the increased introduction in electricity production of

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renewable sources increases this volatility even more due to its seasonal production effects [3,4], turning necessary to use futures to turn prices less volatile, or else, for hedging purposes. However, the literature also points that renewable energy generation depresses electricity spot prices [5].

This research studies the price formation process on the Iberian Electricity Market (MIBEL). The issue is addressed using a disaggregated analysis of the relation between the futures and spot markets, uncovering the comovements and lead-lag relationships across markets. Traditionally, only simple correlation analysis is used to explore the links between spot and futures prices or to explore the dynamics of spot prices and portfolio compositions [6]. Literature on the dynamic relation between spot and futures markets is particularly extensive and it focuses mainly in stock markets. For commodity markets mainly addresses the crude oil market. The liberalization of electricity markets across Europe and their continuous and significant development suggest that an analysis to its efficiency would provide insightful results.

The cost-of-carry model [7] explains the relation between spot and futures markets and states that:

$$F(t)=S(t)\, e^{(r+c-y)(T-t)} \tag{1}$$

Where $F(t)$ is the futures price, $S(t)$ is the spot price; T is the time to maturity, r the risk-free rate, c the storage costs as a proportion of the spot price, and y the convenience yield; e(.) stands for the exponential function and t the current time period of the futures price determination. The cost-of- carry model assumes that spot and futures markets are perfect substitutes and efficient. Hence, the arrival of new information should affect both markets in the same manner and time, invalidating the emergence of profitable arbitrage opportunities. In a similar spirit, [8] proposed a model of commodity prices that discusses the short-run dynamics of spot and futures prices, and their relation with rates of production and inventories, linking price movements with fundamentals. Equilibrium is attained within a cash market, a futures market and a market for storage.

The cost of carry model implicitly assumes the non-existence of storage restrictions. In the presence of consumption commodities, however, the emergence of a convenience yield means that the equality in the previous arbitrage equation may not hold (in particular, previous research has documented significant deviations from this relation, finding lead-lag relationships between both markets). This is due to the significant consumption value provided by the commodity since the convenience yield reflects market participants' expectations regarding its availability in the future. Thus, as the probability of shortages increases (as well as the existence of low inventories) the higher will be the convenience yield.

Nevertheless, in electricity markets, the assumption of storage capacity is particularly strong. In fact, non-storability is usually referred as a distinct characteristic of electricity. Therefore, as argued in [9], this characteristic rules out the existence of convenience yields and even the applicability of equation (1) to electricity markets. This is an argument also previously provided by [10]. While the latter's develop an equilibrium model of forward prices where pricing decisions are made by physical market participants rather than speculators, the former derives a general pricing framework for non-storable commodities incorporating forward-looking information, thereby establishing a link between spot and forward prices.

Baseline theory thus provides little guidance in our analysis. In particular, no specific theory for the relation between cash and forward prices (such as the cost-of-carry) as generally been accepted, giving little guidance for the dynamics of this relation and even for its existence. [11] conducts a survey of the literature on commodity markets, including the effects of non-storability in the cash-futures prices relation.

An empirical examination to the existence of a relation between spot and futures prices may provide valuable information, in particular for the design of a general pricing methodology for non-storable commodities. Moreover, an identification of this relation over time and for different investment horizons is of paramount importance. We use the Continuous Wavelet Transform (CWT) theory proposed by [12] and [13] and disseminated in economics and finance by [14–16], among many other.

Econometric analysis has until recently been performed within two different dimensions, the most common being the time domain, comprising the regular regression and time series methods, and secondly the frequency domain, used in Fourier methods. While the first approach allows one to gauge the evolution of a given economic variable across time, the second allows measuring the contribution of each frequency (from high to low frequencies, or as usually used, from the short run to the long run) to the behavior of the variable analyzed. However, the behavior of an economic process across time is a mixture of the evolution of a set of events, resulting from the interactions of economic agents and processes at different horizons. Therefore, economists have long agreed that both approaches are complementary. Notwithstanding, usual tools invalidated bridging time and frequency domain analysis in an efficient and simple manner. Contrary to the usual Fourier methods used in frequency domain analysis, the CWT breaks up the time-series into its constituent sinusoids at each frequency without losing information on the signals over time. Such an approach allows to carefully analyzing the evolution of a variable, and the relation between variables in the time-frequency space.

Many applications of wavelets have been made in the literature regarding energy and electricity markets as in [17] where the authors examine the empirical relationship of electricity generation and economic growth in Singapore. [18] propose an improved approach to electricity prices trend-cyclical component filtering, comparing its performance with the ordinary empirical mode decomposition and with the wavelet-decomposition testing the proposed models in electricity markets (the Europe-Ural and the Siberia price zones of the Russian ATS exchange, the PJM exchange of the USA and the APX exchange of the United Kingdom). [19] empirically assess the implicit predictive content of forward prices by means of wavelet-based prediction of two foreign exchange (FX) rates and the price of Brent oil quoted either in US dollars or euros. The relationship between oil prices and sector stock returns is analyzed in [20] using continuous time wavelets.

As such, application of this approach in commodity markets and particularly in electricity markets, has so far, been limited. To our knowledge, [21] conducted an analysis of electricity markets using CWT-related techniques. In particular, they analyze the hypothesis of convergence and integration between six European electricity spot markets, namely, the Omel (which belongs to Mibel), the NordPool, and the APX in the Netherlands, the EEX in Germany, the EXAA in Austria and the French market. They have found evidence that there is no integration between the Iberian spot market and the remaining markets. Thus, our main contribution is in applying a methodology used to uncover different comovements among series, namely between spot and futures prices in the Mibel electricity market, a market that remains unexplored, considering that this commodity in non-storable and thus wavelets allow to uncover the relationship between series across different frequencies. Wavelets allow analyzing coherence and comovement in both short and long-term horizons which is essential for policy makers and investors that look for series degree of dependence. Additionally, they allow to surpass the major overcomes of linear techniques and the continuous wavelet transform (CWT) was introduced to overcome the disadvantages of short time Fourier transforms. Wavelets, besides providing portfolio diversification benefits, allows the analysis of under and overreaction, as well as lead and lag effect examination between spot and futures markets.

The Iberian market is a pool-based electric energy market, where producers submit to the market operator selling bids (energy blocks and their corresponding minimum selling prices), and consumers submit to the market operator buying bids (energy blocks and their corresponding maximum buying prices). Afterwards, the market operator clear the market using an appropriate market clearing procedure that results in hourly energy prices and accepted selling and buying bids. In this regard, price forecasting is required by producers and consumers, since both use day-ahead price forecasts to derive their respective bidding strategies to the electricity market. Hence, accurate price estimates are crucial for producers to maximize their profits and for consumers to maximize their utilities. However, forecasting electricity prices is difficult because unlike demand series, price series present such characteristics as non-constant mean and variance, heteroscedasticity and significant outliers (due to seasonality, the constant balance between production and consumption, and environmental dependencies). Thus, electricity price forecasting is essential for decision-making mechanisms of market participants to survive in the deregulated and competing commercial environment. The wavelet transform convert a price series in a set of constitutive series. These series present a better behavior (more stable variance and no outliers, due to the filtering effect of the wavelet transform) than the original price series, and therefore, they can be predicted more accurately.

Existing studies have offered different views regarding the lead-lag relationships between spot and futures, but considering other energy markets like oil. For a recent literature review, please see [22]. Being the lead-lag relationship able to capture the volatility patterns and their implications for price forecasting and market efficiency, fundamental to understand oil price dynamics and their implications for the real economy (being all economies dependent on electricity). Therefore, the main motivation of this analysis is to offer scholars, investors and electricity market participants, an understanding of price behavior, as they seek to assess the evolution and changing nature of electricity price dynamics. Understanding electricity price behavior and insights from the field are very important for the economies. Economies are tightly connected to the economic performance of industries reliant and dependent of electricity [23], being electricity one of the major cost factors for businesses. The Iberian market is no exception, being these two economies interconnected regarding the electricity market.

Results seem to suggest that prices are generally in-phase. However, one can observe certain periods where futures prices seem to lead spot prices. Periods with spot prices leading futures prices are also observed but they seem to be more short-lived and occur at higher frequencies For contracts with longer maturities (Q+3, Q+4 and Y+1), the results are somewhat more mixed, and one can observe transitory periods where the spot leads the futures market, and periods where the opposite occurs. In financial terms, future prices depend over the evolution of the spot and should equal it when contracts reach their maturity date. A commodity's spot price is the price at which the commodity could be traded at any given time in the marketplace. In contrast, a commodity's futures price is the price of the commodity in relation to its current spot price, time until delivery, risk-free interest rate and storage costs at a future date. In the case of electricity it is not storable, at least at affordable prices and thus huge differences among futures and spot prices emerge. Understanding lead-lag relationships between spot and future prices allows investors to hedge against the risk of a very volatility commodity like electricity allowing them to also speculate in these markets. Moreover, the statistically observed correlation that future prices seem to lead spot prices is, at a certain degree, a contradictory economic relationship if future prices should be leaded by spot prices and not the other way around. However, futures in electricity markets are used for hedging purposes provided the volatility of the spot and its non-storability.

Thus observing relationships at different frequencies allows to uncover these different relationships, warning investors from the best opportunities raised in the market and allowing them to hedge considering the most damaging attitudes in face of risk exposure at different investment frequencies. Also, understanding volatility dynamics is of vital importance as they help to recognize the behavior and patterns exhibited by electricity prices during such occasions [4, 24], and they need to be considered by investors when trying to predict and adjust investment and planning strategies. The shape of the futures curve is important to commodity hedgers and speculators, provided that both care about whether commodity futures markets are contango markets or normal backwardation markets. While approaching contract maturity, it is expected that the futures price must converge toward the spot price, being the difference called the basis. Therefore, if they do not converge on maturity, anybody could make free money with an easy arbitrage (profiting with no additional investment), turning the most rational futures price the expected future spot price. Contango (negative basis) occurs when the futures price is above the expected future spot price, implying that futures prices are falling over time as new information brings them into line with the expected future spot price. On the other side, backwardation (positive basis) happens when the futures price is below the expected future spot price, being this desirable for speculators who are net long in their positions (willing to have futures prices increasing). Regulators could in turn see how they can limit and avoid contango and backwardation in electricity markets, since wavelets allow to see these lead-lag relationships and at different frequencies in time, permitting a correct intervention in the market by policy makers to avoid speculation and respective price effects.

This paper provides a novel analysis on two different grounds: first, it conducts an analysis of the price formation process of the Iberian Electricity Market; second, an analysis in the time-frequency space is performed, uncovering a rich set of information and stylized facts on the relation between the futures and spot markets. The remainder of the paper is as follows. Section 2 presents a brief note on the methodology used. Section 3 is dedicated to the main empirical results and section 4 concludes.

2. Methodology

The continuous time wavelet transform (CWT) technique expands a time series into a time frequency space where oscillations can be seen in a highly intuitive way. As such, this technique exposes regions with high common power and further reveals information about the phase (lead or lag) relationship, where the long run may be observed at lower frequencies. As also stated in [20], wavelets allow us to infer about the under reaction of investors to new public information in the short run [25] or overreaction (for longer horizons) hypothesis [26], as well as to see how these vary due to different investment horizons [27]. In this paper, we resort to the continuous wavelet transform to investigate the comovements within the Iberian electricity market. Starting from a mother wavelet $\lambda(t)$, the continuous wavelet transform of a given time series $x(t)$ equals:

$$W_x(\tau, s) = \int_{-\infty}^{+\infty} x(t)\frac{1}{|s|}\lambda\left(\frac{t-\tau}{s}\right)dt \tag{2}$$

Thus, the continuous wavelet transform of the series is obtained by scaling and translating the mother wavelet through the factors s and τ respectively, allowing one to project the signal of the original series $x(t)$ into the time-frequency space. Low frequencies are assessed when $|s| > 1$ as the wavelet gets becomes more stretched, while higher frequencies are assessed if $|s| < 1$.On the other hand, the translation operation allows the wavelet to shift its location in time, shifting to the right whenever $\tau > 0$ and left when $\tau < 0$. In this paper, we will make use of the Morlet wavelet, since, as shown in [16] it represents the best compromise between time and frequency.

The application of the continuous wavelet transform theory allows us to compute some useful measures. One of these measures is the wavelet power spectrum (*WPS*) which measures the contribution of each frequency to the power of the series over time. When integrated over frequencies this equals the variance of the series:

$$WPS_x(\tau, s) = |w_x(\tau, s)|^2 \tag{3}$$

Another measure of particular interest is the wavelet coherency, a measure analogous to the correlation coefficient in the time domain, which measures the regions in the time-frequency space where both series display similar behavior:

$$R^2_{xy} = \frac{\left|S\left(s^{-1}W_x(\tau, s)W_y(\tau, s)\right)\right|^2}{S(s^{-1}|W_x(\tau, s)|^2).S(s^{-1}|W_y(\tau,s)|^2)}, 0 \le R^2_{xy} \le 1 \tag{4}$$

Here S is a smoothing operator in time and scale (see Grinsted et al. (2004)). The analysis of lead-lag relationships in this framework is relatively simple since one can separate the real and imaginary components of the wavelet coherency and compute the angle of the wavelet coherency called the phase difference

$$F(\tau, s)\tan^{-1} = \left\{\frac{\Im\left(S(s^{-1}W_x(\tau, s)W_y(\tau, s))\right)}{\Re\left(S(s^{-1}W_x(\tau, s)W_y(\tau, s))\right)}\right\}.$$

3. Main Results

The analysis is based on daily prices for baseload futures contracts with monthly, quarterly and yearly maturities, namely, FTB-M, FTB-Q and FTB-Y, for the two months, four quarters and on year ahead. Spot prices are represented by the daily SPEL baseload price index. All series were retrieved from Omip website and span the period from 3-July-2007 to 02-02-2017, covering the evolution of both spot and futures markets since the inception of futures trading.

Figure 1 exhibits the evolution of spot and futures prices for the contracts analyzed.

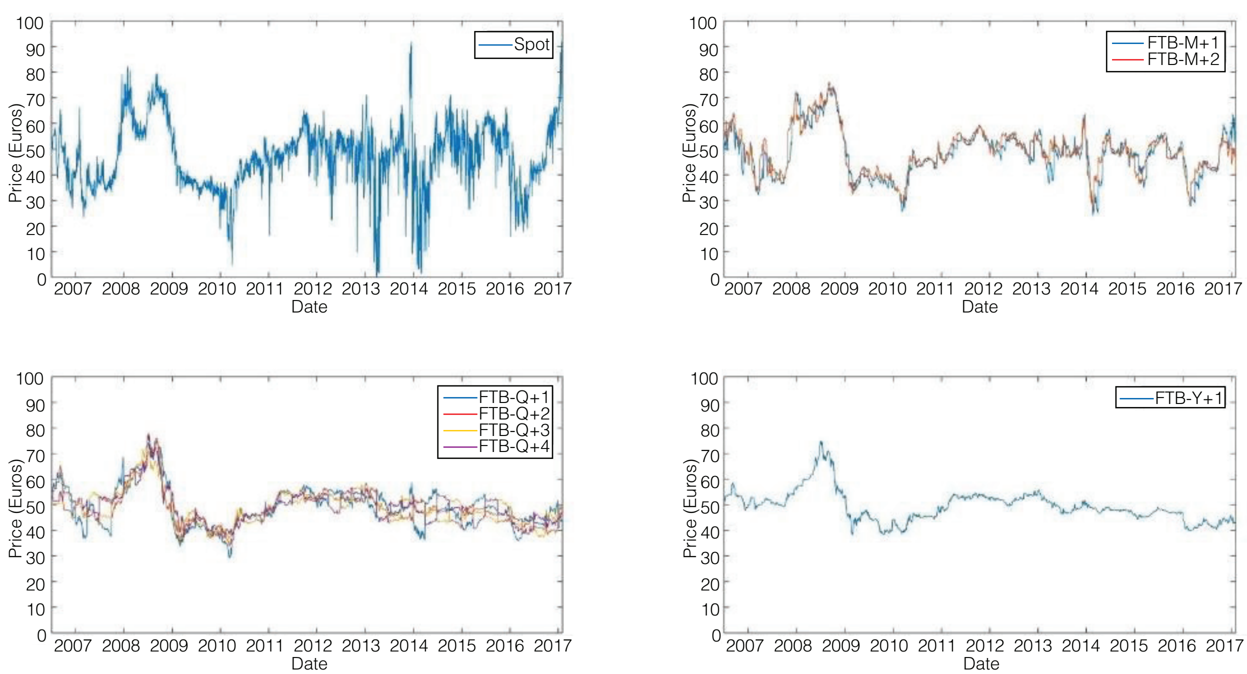

Figure 1: Spot and Futures Prices in the Mibel electricity market

The figure suggests that spot prices are significantly more volatile than future prices. This stylized fact is one of the most well-known characteristic of electricity prices. As noted by [28], among others, the reason for this behavior is usually attributed to the nature of electricity production and consumption and, even more important, to the existence of significant seasonal effects in electricity supply and demand, and to the non-storability of electricity. Price volatility then tends to emerge because inventories cannot be used to smooth supply and demand mismatches. However, a more detailed volatility analysis can be conducted through the visualization of the Power Spectrum of each contract, presented in Figure 2.

In Figure 2, the black contour shows regions with significant power at the 5% significance level, estimated trough Monte Carlo simulations. The cone of influence is also displayed with a dashed black line, indicating regions affected by edge effects and so any interpretation must be cautiously performed. Areas with red color depict higher volatility. The figure may suggest that volatility in electricity prices is higher at high scales (lower frequencies), in particular, power tends to be higher from scales of 64 days (2 months) onwards. Significant areas of price volatility in futures prices are observed between the years of 2007 until 2009, around the period of significant volatility in global financial markets and the spread of the global economic crisis. We may also conclude that around these years, volatility was spread across all frequencies, namely for the contracts with longer maturities, perhaps reflecting not only higher uncertainty related to future prices but also higher speculation in the futures market.

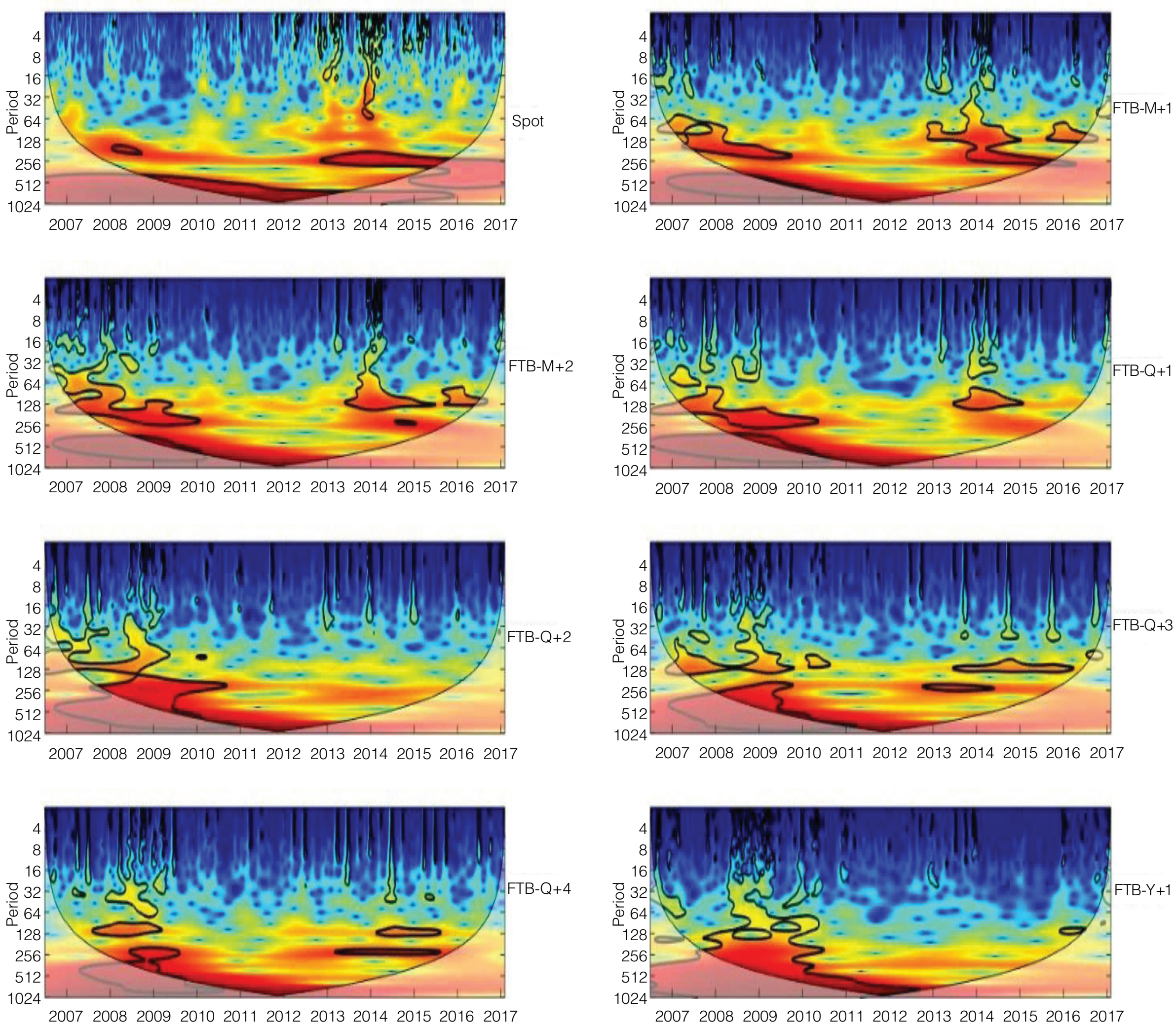

Figure 2: Wavelet Power Spectrum of Spot and Futures Prices

Turning now to the association between spot and futures prices, we study the potential relation between the two markets and its dynamics (lead-lag effects), thus the price formation mechanism. Figures 3 presents the estimated wavelet coherency and phase-difference between spot prices and the different futures contracts. Arrows represent phase-differences. An arrow pointing right means that both series are in-phase (i.e., the series analyzed have positive local correlation, moving in the same direction), while an arrow pointing left means that series display an anti-phase relation (i.e. negative comovement). In addition, an arrow pointing down

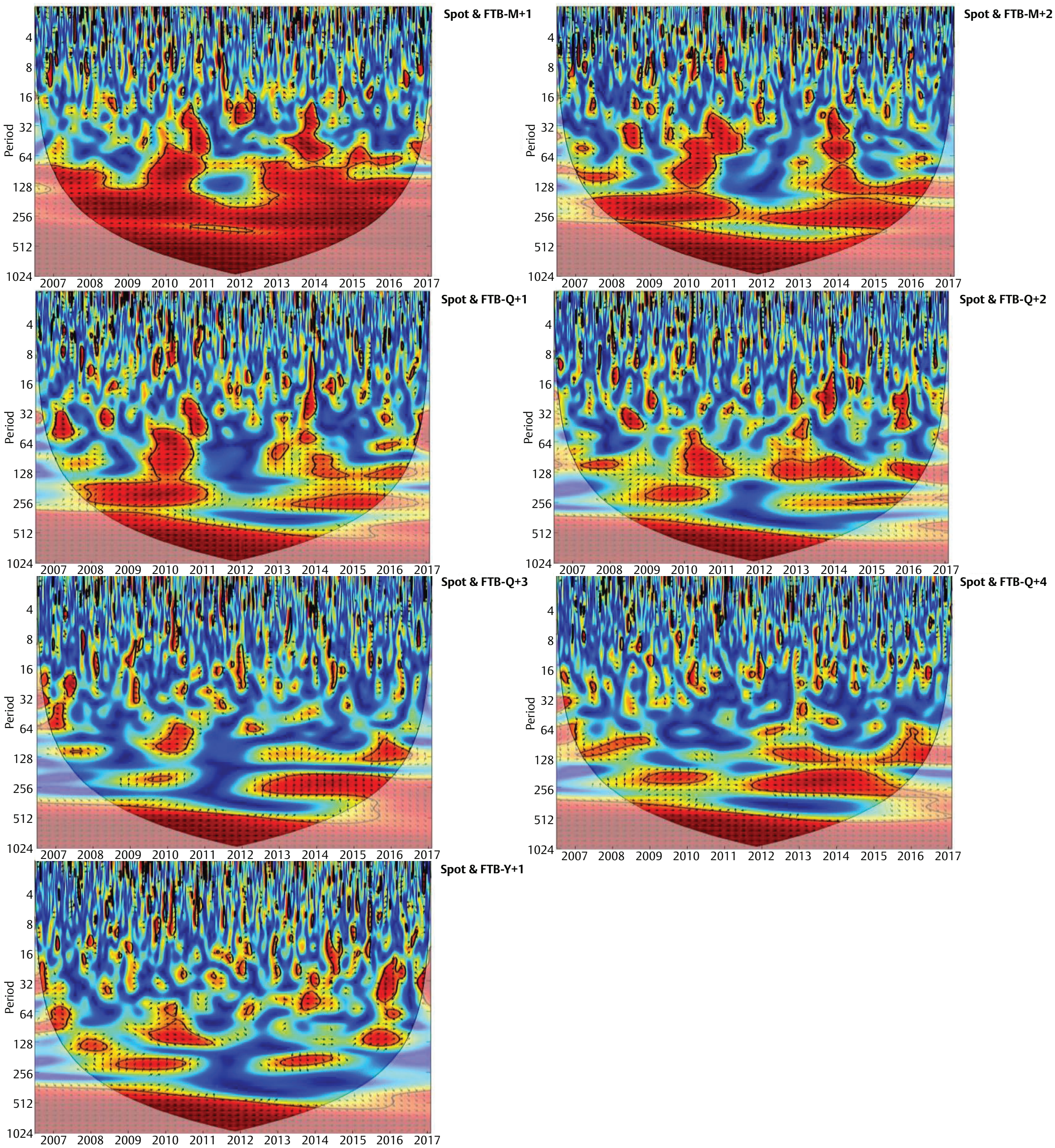

Figure 3: Wavelet Coherency of Spot and Futures Prices

means that the spot price leads the futures price while an arrow pointing up means the opposite. Black contour lines show regions with significant coherency at the 5% significance level, with significance assessed through Monte Carlo simulations with generated surrogate datasets assuming an AR(1) with the same autoregressive structure as the original electricity prices. Color code for coherency ranges again from blue (low coherency) to red (high coherency).

Theory predicts that a no-arbitrage relation usually referred to as cost-of-carry, ties spot and futures prices. As this relation assumes the possibility of economic storage, some literature often doubts of its applicability to electricity markets or even of the existence of a long-run relation between spot and futures markets. The results from wavelet coherency strongly suggest the existence of this relation. Coherency between the spot, the monthly futures contract, and the front-quarter prices shows a strong degree of association but at lower frequencies, with all action appearing in scales higher than 64 days. In particular, the relation between spot and monthly contacts prices is markedly strong across the entire period in lower frequencies. For the remaining maturities, one is able to identify several periods with significant correlation, in particular, during the 2008-2011 period and from 2013 onwards, although correlation seem to decrease somewhat.

Looking to phase-differences, the results seem to suggest that correlation between spot and futures markets is positive, with arrows pointing right in all areas with significant correlations. Moreover, this result seems to be consistent across all maturities. Additionally, the results seem to suggest that prices are generally in-phase. However, one can observe certain periods where futures prices seem to lead spot prices, in particular in monthly contracts within the 128-512 frequency band (with this effect being more pronounce for the M+2 maturity). Periods with spot prices leading futures prices are also observed but they seem to be more short-lived and occur at higher frequencies (16-32 frequency band). The same conclusions seem to hold for the front-quarter contract. For contracts with longer maturities (Q+3, Q+4 and Y+1), the results are somewhat more mixed, and one can observe transitory periods where the spot leads the futures market, and periods where the opposite occurs. The statistically observed correlation that future prices seem to lead spot prices is, at a certain degree, a contradictory economic relationship if future prices should be leaded by spot prices and not the other way around. This is so, if it is expected that future prices depend over the evolution of the spot. However, futures in electricity markets are used for hedging purposes provided the volatility of the spot and its non-storability. Thus observing relationships at different frequencies allows to uncover these different relationships, warning investors from the best opportunities raised in the market and allowing them to hedge considering the most damaging attitudes in face of risk exposure at different investment frequencies.

4. Conclusions

This paper assesses the price formation mechanism of the Iberian Electricity Market. In particular, the evidence on the dynamic relation between the spot and the futures market prices is provided, empirically analyzing whether one systematically leads (or lags) to the other. The analysis uses a new approach to bring a full time-scale vision of the comovements between markets, explicitly considering the different time-scales within which agents operate in the market, and where the dynamic relations may constantly change.

Traditionally, the literature has relied on cointegration methods to explore the possible existence of a long-run relation between spot and futures prices in electricity markets, and correlation analysis or causality tests to observe lead-lag relationships between them. In this paper, the Continuous Wavelet Transform theory is used to address both issues, resorting to complex wavelet coherencies and phase-differences. This framework uncovers valuable information at different investment horizons that would remain unknown under traditional methodologies.

Results suggest the existence of strong positive comovements between both markets but within an investment horizon longer than 64 days, while comovements at low frequencies are rather weak. The lead-lag relation between markets is time-varying and frequency-dependent. Although one can generally observe that prices tend to be in-phase, in particular for futures prices with shorter maturity, our results seem to identify periods where futures lead spot prices, but also, periods where the opposite occurs (although this occurring at higher frequencies and appearing to be more short-lived). Notwithstanding, this paper confirms the existence of a spot-futures relation in electricity markets, thereby confirming the need for new tests and analysis to uncover the determinants of this relation. It also provides useful insights for market regulators and electricity investors in spot and futures prices allowing good inferences and forecasting's at different time frequencies.

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