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Energy price dynamics in the U.S. market. Insights from a heterogeneous multi-regime framework

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ABSTRACT

Energy is a key input in investment decision making with a well-known effect on economic growth. Inelasticity of energy demand urges an understanding of its price dynamics. This paper makes a joint analysis of the price of oil, natural gas, and electricity in U.S. markets using a multi-regime specification that captures the stylized facts of energy prices. Oil and natural gas returns have similar regime dynamics and are well characterized by a high and low volatility regime. Electricity returns have to be parameterized with more regimes: a low volatility, a price spike, and a mean-reverting regime. The California crisis period stands out as a sole regime with extremely high volatility. Our methodology allows the synchronization among regimes to be studied and we find that electricity prices tend to be synchronized in U.S. wholesale markets, while natural gas returns show synchronization with electricity returns in the low volatility regime.

1. Introduction

Energy is a strategic commodity with great economic value. Several works have documented that energy price changes have a direct impact on the economy. In his pioneering work, Hamilton [1] shows that oil price hikes partially accounted for every U.S. recession after World War II. Bernanke [2] and Pindyck [3] models show that large oil price movements increase uncertainty about future prices, causing delays in business investments. More recently, He et al. [4] find that electricity price hikes have a contractionary effect on economic development. Therefore, modeling price dynamics and understanding the connection between sources of energy are prominent issues in energy economics [5–9].

Empirical works conclude that regime switching models are a good framework to model energy prices as they present cyclical behavior and price jumps due to imbalances between supply and demand [10–14].

This paper makes a joint analysis of energy prices in U.S. markets — crude oil, natural gas and electricity prices from several geographic zones of the U.S. — using a multi-regime framework. Although previous work has analyzed the interrelation between energy prices, the focus has been on the long-run relation, using cointegration methods [15,7,6,5]. Differently, our study analyzes the cyclical behavior of time series for energy price providing new insights into the existence of common regimes and the synchronization among them. To the best of our knowledge, the joint analysis of sources of energy has not been analyzed in a multi-regime framework.

Our methodology extends the framework of regime-switching models introduced by Hamilton [16] to account for both time series heterogeneity and hidden regimes within a time series. This class of models was developed by Dias et al. [17] and Ramos et al. [18] and is extended to capture particularities of energy prices. An advantage of our methodology is that it recognizes specific regime-switching dynamics of energy prices. This is important because we expect that oil, natural gas, and electricity possess different regime features. For instance, literature has characterized oil dynamics by a low and a high volatility regime [10,14], while three regimes have been used to characterize electricity: the base, the price spike, and the mean-reverting regime [12,13]. Our approach can model oil, natural gas and electricity jointly, but taking into account heterogeneity of regime dynamics. Moreover, it provides insights into the synchronization within regimes. From a methodological point of view, regime-switching models have several advantages over

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traditional approaches to studying synchronization: they account for outliers better than standard methods based on pairwise correlations; they are adequate to portray the behavior of cyclical components like volatility; they can accommodate nonlinearities, and they also account better for the problem of non-normality in returns. In addition, the flexible modeling of observed returns using a mixture of normal distributions makes it more appropriate for non-Gaussian returns [19,20].

The main results are as follow. While oil and natural gas returns show similar cyclical behavior and regime dynamics, natural gas tends to switch more frequently between regimes than oil returns. They are well characterized by a low and a high volatility regime. Although we find regime persistence for these two time series, peaks of high volatility are short-lived.

Electricity is better parameterized by more regimes, such as low volatility, a price spike regime, and a mean-reverting regime, switching frequently between them. The period of California crisis stands out as the only regime with extremely high volatility.

Our approach allows the study of synchronization between regimes. We find synchronization of regimes for different geographic U.S. wholesale electricity markets. Natural gas returns show synchronization with electricity in the low volatility regime.

Our conclusions are relevant for the growing number of players in energy markets that need to understand the joint price dynamics of these commodities. It is widely acknowledged the market power of the energy industry and that firms are better prepared to pass to customers energy price increases than energy price decreases [21].

The structure of the paper is as follows: Section 2 reviews the literature. Section 3 addresses the application of RSM – Regime Switching Models – for energy prices and describes the methodology. Section 4 describes the data and depicts summary statistics. Section 5 reports and discusses the estimates of the models put forward in this research and analyzes the synchronization of energy prices. The article ends by highlighting the main conclusions, limitations of the methodology and avenues for further research.

2. Review of the literature

Several papers have studied the degree of co-movement of energy prices, mainly crude oil and its derivatives, and crude oil and natural gas. Serletis and Kemp [5] examine the cyclical behavior of monthly prices of crude oil, heating oil, unleaded gasoline and natural gas. They measure the degree of co-movement of a time series by the magnitude of the correlation coefficient.

The joint analysis of energy prices has been mostly done with cointegration methods. Serletis and Herbert [6] and Serletis and Rangel-Ruiz [22] investigate whether fuel oil and natural gas share price trends. Serletis and Rangel-Ruiz [22] find a 'decoupling' of the prices of these two sources of energy after the oil and gas deregulation in the U.S., as they try to gain insights into long-term economic relationships.[1] Emery and Liu [24] find that futures prices for electricity and natural gas are cointegrated. Hammoudeh et al. [7] apply cointegration tests to both spot prices and futures prices of WTI (West Texas Intermediate), gasoline and heating oil. Bachmeier and Griffin [25] find that crude oil, coal, and natural gas markets are only very weakly integrated in the U.S. Mjelde and Bessler [8] also use a vector of error correction model to analyze the dynamic price information flows among wholesale spot prices of U.S. electricity and the prices of the major electricity generation fuel sources, natural gas, uranium, coal, and crude oil. Mohammadi [9] examines the long-run relation and short-run dynamics between electricity prices and three fossil fuel prices – coal, natural gas and crude oil – using annual data for the U.S. for 1960–2007. Among the three fuel prices considered (coal, natural gas, and crude oil), he only finds evidence of significant long-run relations between electricity and coal prices.

Our work is related with the strand of literature that has applied Markov RSM (regime switching models) to oil, natural gas and electricity prices [26,27,10,12,28,14]. Energy prices tend to present price spikes usually caused by imbalances between supply and demand. These price spikes are sharper for electricity as there are no inventories to buffer shocks.

Approaches like stochastic jump models have also been used to model energy prices, but studies have concluded that regime switching models present many advantages in modeling the spiky and nonlinear behavior of electricity prices [29,30,11].

Another stylized fact for electricity is that prices tend to converge to long-term equilibrium, which is normally modeled by using a mean-reverting mechanism. Mari [30] advocates that mean reversion is a very important property of electricity price dynamics; it is responsible for reducing prices during spike periods and it allows fluctuation of prices around the long-run equilibrium in normal periods. Distinct mean-reverting mechanisms are experienced in different regimes with higher values in turbulent periods. While there is no disagreement for electricity on this point, the evidence of autoregression (AR(1)) in oil is conflicting. Pindyck [31] shows that the rate of mean reversion for oil, natural gas and coal is slow. Morana [32] suggests that the time series for crude oil prices is featured by fat tail distribution, volatility clustering, asymmetry and mean reversion, whereas Serletis and Herbert [6] could not reject a random walk for oil and natural gas and Ozdemir et al. [33] do not find persistence in oil prices when structural breaks are taken into account.

Initial works on electricity modeling specified a two-regime framework with an autoregressive process of order one within each regime. Deng [26] and Ethier and Mount [27] proposed a two-regime model with mean-reverting AR(1) processes for the log-prices in both regimes. Huisman and Mahieu [12] introduced a three stage regime but with some constraints: the initial jump regime was immediately followed by the mean-reverting regime and then moved back to the base regime. They found that a regime-switching model fits better than a stochastic jump model specification for both mean reversion and spikes. They identify a normal regime that can contain a mean-reverting component. In addition, they identify two extra regimes: the first regime models price jumps, whereas the second models the mean reversion of the process.

3. Methodology

The Markov-switching model by Dias et al. [17] and Ramos et al. [18], labeled HRSM (heterogeneous regime-switching model), is extended to an autoregressive (and mean reversion) framework with multi-regimes. The model is adopted to capture particularities of energy prices, where the dynamics are characterized by normal stable periods with prices fluctuating around a long-run mean.

Regime-switching models offer the possibility to introduce heterogeneous mean-reverting rates and volatilities depending on the state of the system. In modeling electricity prices movements, regime-switching models capture the nonlinearities of the dynamics and distinguish the normal stable motion from the turbulent and spike regimes. The switches between regimes are specified by Markov transition probabilities.

[1] Studies have also analyzed energy prices trends from U.K. samples. Asche et al. [15] use monthly prices of crude oil, natural gas, and electricity to analyze market integration. Panagiotidis and Rutledge [23] also use cointegration methods for the period 1996–2003. Their findings do not support the notion of decoupling of natural gas and oil prices in the U.K.