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Energy prices, multiple structural breaks, and efficient market hypothesis

Chien-Chiang Lee *, Jun-De Lee

Department of Applied Economics, National Chung Hsing University, Taichung, Taiwan

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A B S T R A C T

This paper investigates the efficient market hypothesis using total energy price and four kinds of various disaggregated energy prices – coal, oil, gas, and electricity – for OECD countries over the period 1978–2006. We employ a highly flexible panel data stationarity test of Carrion-i-Silvestre et al. [Carrion-i-Silvestre JL, Del Barrio-Castro T, Lopez-Bazo E. Breaking the panels: an application to GDP per capita. J Econometrics 2005;8:159–75], which incorporates multiple shifts in level and slope, thereby controlling for cross-sectional dependence through bootstrap methods. Overwhelming evidence in favor of the broken stationarity hypothesis is found, implying that energy prices are not characterized by an efficient market. Thus, it shows the presence of profitable arbitrage opportunities among energy prices. The estimated breaks are meaningful and coincide with the most critical events which affected the energy prices.

1. Introduction

Energy market efficiency implies that energy prices respond quickly and accurately to relevant information.[1] Information in the efficient market hypothesis (EMH hereafter) is defined as anything that may affect prices which is unknowable in the present and appears randomly in the future. This random information is the cause of future price changes (Kulish [2]). Examining for mean reversion (trend stationary) in energy prices is one avenue for investigating the EMH (see Fama and French [3]; Narayan [4,5]),[2] and the issue of whether energy prices can be characterized as following a random walk or mean reverting process has important implications. If energy prices are mean reverting, then it follows that the price level will return to its trend path over time and that it might be possible to forecast future movements in energy prices based on past behavior.[3] By contrast, if energy prices follow a random walk process, then any shock to prices is permanent. This means that future returns cannot be predicted based on historical movements in energy prices and that volatility in energy markets increases without bound.

There is a large body of the literature that investigates the stationarity in energy prices using a variety of methodologies (see Table 1). However, most studies in the literature focus on oil price issues or just consider only one kind of energy price. Moreover, previous studies concluded that all kinds of energy prices are non-stationary. Differently, our paper considers five kinds of energy prices: total energy, oil, coal, natural gas, and electricity price. It is also remarkable that no previous study employs panel statistics allowing for multiple breaks in the data generating process of the energy price series.

Variations in energy price, nevertheless, reflect changes in regimes whose primary goal is typically economic development, and of course, this involves changes in energy policy. Thus, one very important reason that previous studies fail to find evidence of stationarity could be that they do not take structural breaks into account. One noticeable characteristic is that energy price series are usually affected by multiple breaks (see Figs. 1–5). There are two important factors when performing tests that allow for structural breaks. First, structural breaks might be associated with some atypical events (both domestic and international, market regulations, and technological advances), such as the oil crises, the Kyoto Protocol, and renewable energy technology (see Lee and Chang [6]). Second, considering structural breaks allows us to obtain more detailed information on the behavior of energy pricing.

This paper contributes to the debate about the validity of the empirical basis of the energy market's EMH in several respects. First, our study attempts to take on board Perron's [7] critique by

* Corresponding author. Tel.: +886 4 22840352; fax: +886 4 22860255.
E-mail address: ccl@nchu.edu.tw (C.-C. Lee).

[1] Fama [47] indicates that an efficient market generates prices, which at any point in time, fully reflect all available information. If the set of all information is restricted to the past prices for financial assets, then the market is said to be weak-form efficient.

[2] Here, we use the terms "random walk" and "unit root" interchangeably throughout the paper (see Chaudhuri and Wu [13] and Narayan [4,5]).

[3] Pindyck [48] indicates that if energy prices are trend reverting, this is consistent with energy being sold in a competitive market where price reverts to long-run marginal cost, which changes only slowly.

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Table 1
Comparison of previous empirical results from various univariate unit root tests for energy prices.

Author(s)	Sample countries	Method	Sample period	Result
Part A: Total energy price				
Bentzen and Engsted [52]	Danish	ADF and PP	1960–1996	Non-stationarity
Vita et al. [53]	Namibia	ADF and Perron [7]	1980–2002	Non-stationarity
Yamaguchi [54]	Japan	ADF, PP and KPSS	1986Q1–2004Q4	Non-stationarity
Part B: Oil price				
Huang et al. [28]	US, Canada and Japan	PP, KPSS, ZA and Hylleberg et al. [62]	1970–2002	Non-stationarity
Maslyuk and Smyth [30]	WTI and Brent	Lee et al. [29]	1991–2004 (Weekly data)	Non-Stationarity
Vita et al. [53]	Namibia	ADF and Perron [7]	1980–2002	Non-stationarity
Holtedahl and Joutz [55]	World oil price	ADF	1955–1995	Non-stationarity
Ferreira et al. [56]	UK	ADF and PP	1990–2002	Non-stationarity
Kaufmann and Laskowski [57],	US	ADF	1986M1–2002M12	Non-stationarity
Rapanos and Polemis [58]	Greece	ADF and PP	1965–1998	Non-stationarity
Part C: Coal price				
Ferreira et al. [56]	UK	ADF and PP	1990–2002	Non-stationarity
Kulshreshtha and Parikh [59]	India	ADF	1970–1995	Non-stationarity
Part D: Natural gas price				
Ferreira et al. [56]	UK	ADF and PP	1990–2002	Non-stationarity
Zachariadis and Pashourtidou [60]	Cyprus	ADF and Perron [7]	1960–2004	Non-stationarity
Part E: Electricity price				
Vita et al. [53]	Namibia	ADF and Perron [7]	1980–2002	Non-stationarity
Holtedahl and Joutz [55]	Taiwan	ADF	1955–1995	Non-stationarity
Ferreira et al. [56]	UK	ADF and PP	1990–2002	Non-stationarity

Note: ADF denotes Augmented Dickey Fuller [14] test. LP denotes Lumsdaine and Papell [18] test. PP denotes Phillips and Perron [15] test. KPSS denotes Kwiatkowski–Phillips–Schmidt–Shin [16] test. ZA denotes Zivot and Andrews [17] test. M and Q denotes monthly and quarterly data, respectively.

controlling for structural instability in the data generating process of the variables. For that purpose, we employ the panel data stationarity test of Carrion-i-Silvestre et al. [1] (CBL hereafter), which assumes a highly flexible trend function by incorporating an unknown number of changes in level and slope. This test is thus more general than the panel unit root test by Im et al. [8] that only incorporates a maximum of two changes in level, but not in the slope coefficient. This can be very restrictive for energy price series which generally show a trending behavior and have been subject to several infrequent shocks of great magnitude such as the oil shocks of the 1970s.

Second, we focus on total energy price and four kinds of disaggregated energy prices (including oil, coal, natural gas, and electricity) and use a wider range of panel unit root tests with and without breaks. Third, the method of CBL [1] is able to determine individual fixed effects and/or individual-specific time trends. It also has the capability to consider multiple structural breaks positioned at different unknown dates in addition to a different number of breaks for each individual effect. Fourth, we focus on the organization for economic cooperation and development (OECD) countries which are thought to be the ones more likely to suffer the consequences of the sharp rises in energy prices in the 1970s.

Fifth, both under the null of a unit root as in Im et al. [9] (IPS hereafter) and Maddala and Wu [10] (MW hereafter) and under the null of stationarity as in Hadri [11], these tests allow us to consider a higher degree of heterogeneity in the cross-sectional dynamics and show higher power than their time series equivalents. However, it should be noted that the limited distribution of all these tests relies on the assumption of cross-sectional independence, but this is an overly strong restrictive assumption. Moreover, allowing for structural breaks in the panel unit root tests, such as those of IPS [9] and Levin et al. [12] (LLC hereafter), would be quite difficult, in large part because the distribution of these panel unit root tests with structural breaks critically depends on nuisance parameters which indicate their location, as noted by IPS [9].[4] Unlike most previous studies, we allow for more general forms of cross-sectional correlation than that implied by the traditional cross-sectional demeaning of the data, which assumes a common factor affecting all units with the same intensity.

Finally, to date there is a large body of the literature that investigates the EMH of stock prices (see Fama and French [3]; Narayan [5]; Chaudhuri and Wu [13]).[5] However, few studies in the literature test the EMH of energy prices. Accordingly, the main objective of this paper is to investigate whether energy prices can be characterized by the EMH or not.

The remainder of this paper is organized as follows: Section 2 provides a brief summary of the literature. In Section 3 we describe the econometric methodology of CBL [1]. Section 4 reports the data and empirical results. Finally, in Section 5 we summarize our findings and attempt to draw some policy implications.

2. Literature review

Kulish [2] proposes a novel mathematical model of price information, which is based on the assumption that no instantaneous propagation of information is possible within the market. He shows that a phase-lagging market is never either fully efficient or fully inefficient due to the finiteness of the frequency of news acting upon the market. Moreover, a standard approach in time series studies of energy demand is to first test for the stationarity of energy price and, conditional on the finding for the order of integration, proceed to examine whether energy price is co-integrated with other variables of interest. Most studies employing univariate unit root tests without structural breaks – typically the Augmented Dickey–Fuller [14] (ADF hereafter), Phillips–Perron [15] (PP hereafter), and the Kwiatkowski–Phillips–Schmidt–Shin [16] (KPSS hereafter) unit root tests – conclude that energy price is integrated of order one, I(1).

To address the low power of univariate unit root tests, recent developments in unit root testing have progressed in two directions. The first is to accommodate structural breaks. Ever since

[4] Dinda and Coondoo [49] find that the IPS test renders overwhelming evidence of non-stationarity in both per capita GDP and CO_2 emission levels.

[5] Narayan [5] uses the panel LM unit root test developed by Im et al. [8], which has the advantage of utilizing both panel data and structural breaks when testing for a unit root.