Evolving Time-varying Market Efficiency of Energy Stock Market

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ABSTRACT

Energy stocks have become an essential segment of the investment portfolios of both households and institutional investors. This study investigates the dynamic aspect of evolving weak-form efficiency in six energy stock markets: those of the United States (US), Canada, China, Australia, India, and Saudi Arabia. The generalized autoregressive conditionally heteroskedastic in the mean GARCH-M(1,1) method is applied, alongside the state-space time-varying approaches and the Kalman-filter assessment, to detect the evolving efficiency for periods ending in November 2019.

The empirical results reveal that the studied markets undergo various extents of time-varying efficiency, containing periods of efficiency enhancement as well as periods of deviation from efficiency. Meanwhile, the 2007–2009 global financial crisis and the 2015 changes in the energy sector—in addition to other contemporaneous crises—have a profound influence on the timeline of market efficiency evolution.

Overall, all of the markets gradually became more efficient, apart from India’s energy market as a result of the current energy crisis in India. Amid the energy markets explored in this study, the US energy market was found to be the most efficient.

Keywords: Energy stock market, GARCH-M, Time-varying efficiency, Kalman-filter

ÖZ

Enerji hisse senetleri gerek bireysel gerekse kurumsal yatırımcıların portföylerinde önemli bir yer kapsamaktadır. Bu çalışmada, ABD, Kanada, Çin,Avustralya, Hindistan ve Suudi Arabistan zayıf form etkinlik dinamik açıdan incelenmiştir. Genelleştirilmiş Otokoşullu Değişen Varyans Otoregresif Ortalama GARCH-M(1,1) metodu uygulanmış aynı zamanda zamanla değişen parametreler içeren Durum-Uzay (State-Space), yaklaşımı Kalman filtresi tahminleri ile Kasım 2019 dönemini kapsayacak şekilde etkinlik tespit edilmiştir.

Ampirik bulgular piyasaların farklı zaman değişim etkinliği içerisinde, faklı dönemlerde etkinlikten saptanmakla beraber aynı zamanda da yükselmeler de gözlenmektedir. 2007-2009 global kriz dönemi içerisinde ve 2015'te enerji sektöründe yaşanan değişim ve devam eden krizler sürecinde piyasa zaman eğrisi etkinlik oluşumuna önemli vurgu yaptığı gözlemlenmiştir.

Bütünsel olarak, piyasalar daha etkin olmasına karşın Hindistan Enerji Piyasası ülkede yaşanan kriz neticesinde etkinlik gösterememiştir. Çalışmada ele alınan ülkeler içerisindeki enerji piyasalarında en etkin piyasa ABD olarak belirlenmiştir.

Anahtar Kelimeler: Enerji Hisse Senedi Piyasası, GARCH-M, Zaman-değişim Etkinliği, Kalman-filtresi

To my lovely family

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Negar Fazlollahi
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INTRODUCTION

1.1 Introduction

The efficiency of the security market has gained considerable attention among investors. Establishing and promoting an efficient security market enables investors to make appropriate investment decisions and better accomplish their asset allocation and portfolio risk management. The efficiency of the security market is a major factor to the improvement of the country's financial and economic sectors.

1.2 Background and Context of the Study

1.2.1 The Efficient Market Hypothesis

The issue of the Efficient Market Hypothesis (EMH) in relation to the stock market, the bond market, and, particularly, within the context of weak-form efficiency has been debated in many studies, including (Awad & Daraghma, 2009; Alexeev & Tapon, 2011; Chiwira & Muyambiri, 2012; Mazviona & Nyangara, 2013; Al-Khazali & Mirzaei, 2017; Gil-Alana, Gupta, Shittu, & Yaya, 2018; Mensi, Tiwari, & Al-Yahyaee, 2019).

The inefficiency of the market makes it possible to forecast returns of security through investigating historical data, picking the undervalued and overvalued securities, and, hence, bringing arbitrage opportunities into existence. In the case of efficiency, capital will move to the most productive investments. Studies have also illustrated that mature markets tend to have weak-form efficiency features, while emerging markets display different results and, hence, mostly lean toward a departure from weak-form efficiency (Abdmoulah, 2010). Other studies showed the degree of association of efficiency into market size and economic development (Charfeddine, Khediri, Aye, & Gupta, 2018).

1.2.2 The Efficiency of the Energy Market

The efficiency of the energy stock market has attracted much attention (Alvarez-Ramirez, Alvarez, & Rodriguez, 2008; Alvarez-Ramirez, Alvarez, & Solis, 2010; Wang, Wei, & Wu, 2011; Wang & Wu, 2012, 2013; Khediri & Charfeddine, 2015; Kristoufek, 2019) through with a concentration on oil prices and a few kinds of energy prices. However, focusing on the efficiency of the energy market across all types of energy prices is a gap in the existing literature.

The efficiency of the energy market is defined as energy prices responding instantly to available information in the market (Lee & Lee, 2009; Alvarez-Ramirez et al., 2010; Wang & Wu, 2013; Górska & Krawiec, 2016; Mensi, Tiwari, & Yoon, 2017; Jebabli & Roubaud, 2018; Ghazani & Ebrahimi, 2019; Kristoufek, 2019).

In an efficient energy market, energy price movement is random walk, and the shocks tend to be permanent; as such, anticipating future returns is not possible. In contrast, in an inefficient market, energy prices pursue a mean reversion movement, and any given shocks to prices are temporary. Thus, there is room to gain abnormal returns in these exploitable opportunities.

In addition, energy markets naturally possess more nonlinear properties than do other markets (Serletis & Andreadis, 2004; Tabak & Cajueiro, 2007; Alvarez-Ramirez et al., 2010; Reboredo, 2010; Zhang, 2013; Zhang, Zhang, & Zhang, 2015; Geng, Ji, & Fan, 2017), and thus, identifying the efficiency of energy markets present various challenges to researchers.

Although many studies have investigated the efficiency of the energy market, a majority focus on the overall efficiency of an entire estimation period, and evaluating efficiency at a given point of time (Serletis & Rosenberg, 2007; Elder & Serletis, 2008; Cunado, Gil-Alana, & Perez de Gracia, 2010; Wang & Yang, 2010; Ozdemir, Gokmenoglu, & Ekinci, 2013; Lean & Smyth, 2015; Mensi et al., 2017). Hence, exploring the efficiency of the energy market with concentration on time-varying features is another gap in the literature. As energy prices have been marked by substantial price movements in recent years, it is an opportune time to enhance the existing studies on the degree of dynamic efficiency in the energy market.

Therefore, the current research question is whether energy markets are evolving into efficiency.

1.3 Implications of the Study

Perceiving the evolution efficiency of energy market is an important issue for policy makers as energy plays a fundamental part in the world economy, due to the linkage of energy sector to economic stability and economic growth. In the study done by Balsalobre-Lorente, Bekun, Etokakpan and Driha (2019) the two-way causality detected among natural gas consumption and economic growth for Iran, leading to promoting more efficient usage of natural gas for the purpose of achieving more economic growth.

Over the past century, the energy sector has been counted as an essential driver of industrial growth since it provides fuel to power the rest of the economy. Thus, the new strategies of energy sector target the more concentration on market-oriented low-carbon energy sector ones (Ehigiamusoe & Lean, 2019), which is linked to lower the overall consumption and energy consumption, also higher the energy efficiency (Hajko, Sebri, Al-Saidi, & Balsalobre-Lorente, 2018).

Recently, the importance of information and communication technology and financial development in CO_2 emission and economic growth has been explored for G7 countries in the study by Raheem, Tiwari, and Balsalobre-Lorente (2020). They promoted the policies that focus on boosting economic growth without intensifying carbon emissions.

On the financial strands, energy price movements have a crucial effect on the performance of most sectors in the economies (Lescaroux & Mignon, 2008). Thus, the degree of efficiency will govern the trading and investment techniques to construct a diversified portfolio.

1.4 Aims of the Study

This study aims to explore the dynamic of weak-form efficiency in energy stock markets, using energy sector price indices to determine whether the energy markets of the studied countries are becoming more efficient over time.

1.5 Contributions of the Study and Gaps in the Literature

The research contributes to the debate of weak-form efficiency of the energy market in three aspects:

First, it focuses on the entire energy stock market. Energy stocks refer to the shares of companies that are related to producing or supplying energy. These stocks cover all companies involved in exploring, developing, drilling, and refining oil and gas;

similarly integrated power utility firms; and those related to coal and renewable energy. Because investment decisions in the energy sector are a worldwide concern, as energy is the primary industry in the world, having sales of above $2 trillion annually (Nemet & Kammen, 2007). Consequently, investing in energy stocks has attracted a lot of attention because of the size, potential for future growth, diversity, future earning, and potential income of the energy market.

Also, investors have a wide variety of choices to achieve exposure to the energy sector, from upstream oil and gas exploration companies and the coal industry to alternative and renewable energy. They can invest based on their views and preferences about the growth and earnings prospects through the value chain. Thus, understanding the level of market efficiency in the energy stock market plays a dominant role in financing decisions.

In sum, the study focuses on energy by addressing the entire energy sector, rather than concentrating mainly on crude oil prices or a few kinds of energy prices. To achieve this goal, energy indices in each market adopted. These energy indices represent the entire market sector, not only oil and gas indices, in order to reflect the overall performance of the sector. There are a number of studies focusing on crude oil and natural gas prices, however none on the whole energy sector.

Second, it examines the energy sector by concentrating on the countries which are thought to be the ones with the highest consumers or producers of energy in the world, according to Enerdata’s Global Energy Statistical Yearbook (2019). As the study tries to explore the performance in the energy sector, and the performance of energy sector is mainly driven by the global supply and demand for energy (Charles & Darné, 2009).

Thus, countries with the largest energy consumption and production have the major role to contribute to the global supply and demand of energy. Despite the existing works on the weak-form efficiency of energy market, no study features all these counties together.

The global energy consumption grew considerably in 2018—up to 2.3%—as a result of the sustainable economic growth and increasing energy demand in China, the world’s largest energy consumer since 2009. The energy consumption of China reached its highest growth since 2012—up to 3.7%—due to enormous industrial demands, power generation, and the rising use of fuel for transportation. Meanwhile, the United States (US)’ energy consumption growth rate reached a record high in 2018—up to 3.5%—partly due to weather conditions.

With respect to global energy production, the main contributors to the upsurge seen in 2018—up to 2.8%— are China and US, which together contributed 54% of energy growth.

Third, the weak-form efficiency of the energy market explored, utilizing the time-varying parameter approach, rather than examining efficiency as a fixed factor throughout the whole sample. As it will be misleading to accept the static manner of market efficiency, as marked by EMH, for energy market—where energy stock prices are tend to be seasonal and quite sensitive to political events—. To this end, the study conducts the Generalized Auto-Regressive Conditional Heteroskedastic in the Mean GARCH-M(1,1) model, alongside the state-space time-varying framework. And verified the test by employing Kalman-filter specification to examine the evolving market efficiency.

Hence, the dynamic efficiency of the energy market over time asserted, rather than declaring efficiency at a given point in time, which leads to biased results. In order words, the ongoing efficiency throughout the whole sample explored in this study. Some studies have measured the time-varying efficiency of security markets before (Rockinger & Urga, 2001; Hall & Urga, 2002; Abdmoulah, 2010; Charfeddine & Khediri, 2016; Charfeddine et al., 2018), but no study has precisely measured the time-varying efficiency of the energy market with this methodology.

Meanwhile, to better represents the periods of efficiency/ inefficiency in energy returns the study employs the approach used by Charfeddine et al. (2018); to examine the development of the t-statistic over time for the null hypothesis of β_{it} = 0, against the alternative of $\beta_{it} \neq 0$. Based on our knowledge, no study examined the energy market by providing this approach.

Given the importance of investing in the energy market, it is essential to address the above gaps in the literature.

1.6 Scope of the Study

The study concentrates on the energy sector by selecting the countries that are the highest consumers or producers of energy in the world.

1.6.1 Total Energy Consumption

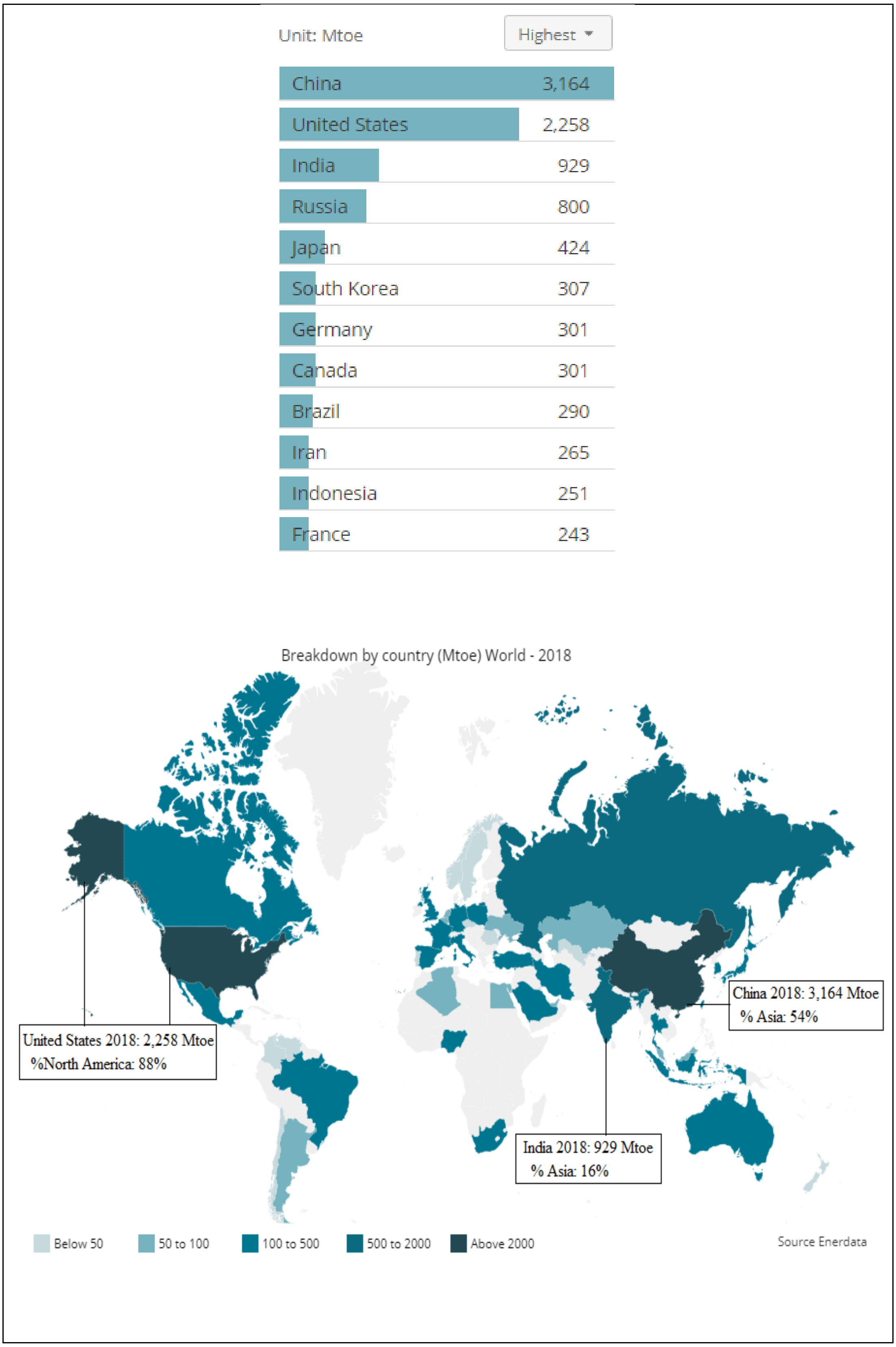
Concerning the energy consumption, the top panel of Figure 1 exhibits the twelve countries that own the World’s highest total energy consumption according to Enerdata’s Global Energy Statistical Yearbook (2019). Those of China, US, India, Russia, Japan, South Korea, Germany, Canada, Brazil, Iran, Indonesia, and France.

China has the highest consumption of energy with 3,164 million or mega tons of oil equivalent (Mtoe).

Moreover, the visual presentation of the world's energy consumption illustrated in the base panel of Figure 1. The breakdown of countries clarifies by different shades of blue, indicating the amount of energy consumption of each country.

Besides, the top three countries—China, US, India—having the largest consumption of energy, marked in this figure. China possesses the 54% of energy consumption in Asia, the US owns 88% of energy in North America, and 16% of energy consumption of Asia belongs to India.

The study chose the top three contributors of the global energy consumption: China, US, and India, which together contribute 67% of the World's energy consumption.



China	3,164
United States	2,258
India	929
Russia	800
Japan	424
South Korea	307
Germany	301
Canada	301
Brazil	290
Iran	265
Indonesia	251
France	243

Breakdown by country (Mtoe) World - 2018

Source Enerdata

Figure 1: Total Energy Consumption

Figure 2 reveals the breakdown of the energy market of the selected three countries by different colors. As for China, the higher portion of the energy consumption is coal which accounts for 61%, then oil 19%, gas and electricity 7%, biomass 4%, and heat 1%. Regarding the US, oil accounts for the majority consumption with 36%, followed by gas 32%, then coal 15%, and electricity 5%. In case of India, coal is the main source of energy consumption 44%, then oil 25%, biomass 21%, gas 5%, and electricity 3%.

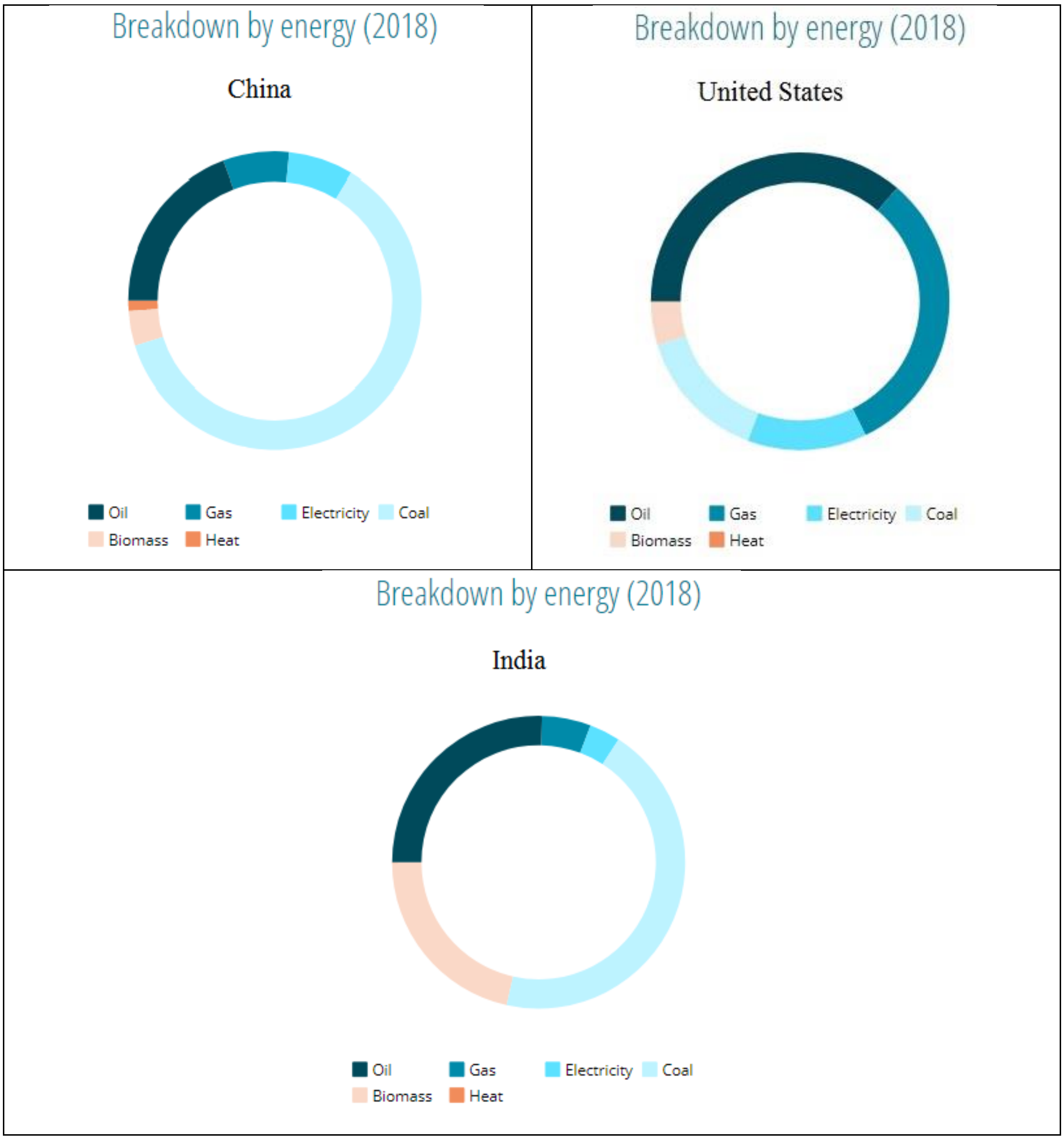


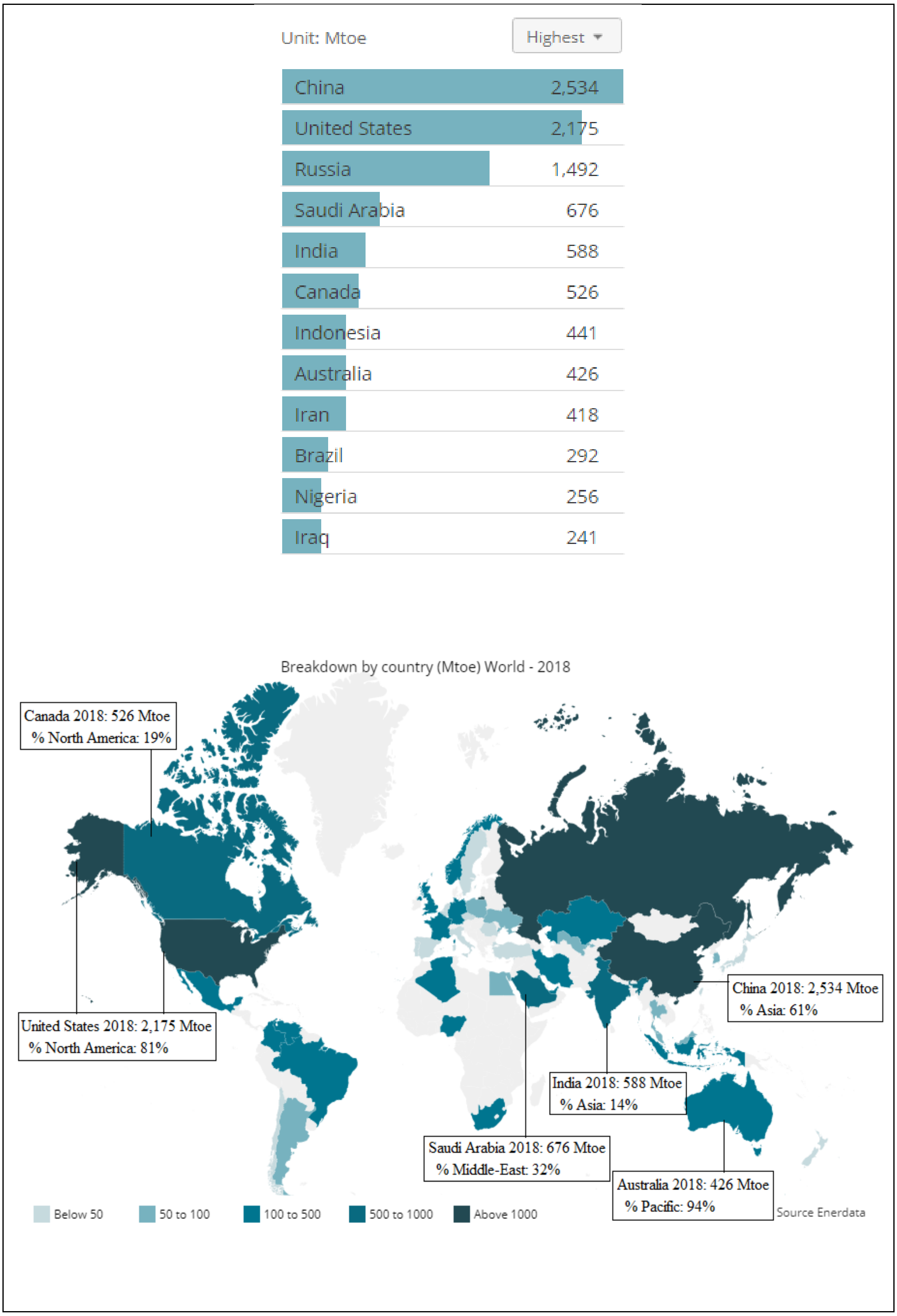
Figure 2: Breakdown by Energy’s Consumption

1.6.2 Total Energy Production

Concerning the energy production, the top panel of Figure 3 displays the twelve countries that own the World’s highest total energy production according to Enerdata’s Global Energy Statistical Yearbook (2019). Those of China, US, Russia, Saudi Arabia, India, Canada, Indonesia, Australia, Iran, Brazil, Nigeria, and Iraq. China has the highest production of energy with 2,534 Mtoe.

Furthermore, the visual presentation of the world’s energy production demonstrated in the base panel of Figure 3. The breakdown of countries illuminates by different shades of blue, indicating the amount of energy production of each country. Besides, the six countries—China, US, Saudi Arabia, India, Canada, Australia—having the largest production of energy, marked in this figure. China possesses the 61% of energy production in Asia, the US owns 81% of energy in North America, Saudi Arabia has 32% of energy in Middle-east, 14% of energy in Asia belongs to India, Canada has 19% of energy in North America, and 94% of energy production of pacific is for Australia.

From the top eight contributors to the global energy production—China, US, Russia, Saudi Arabia, India, Canada, Indonesia, and Australia—the study selected China, US, Saudi Arabia, India, Canada, and Australia, among others, that together account for 69% of the World’s energy production. The omission of Russia and Indonesia are due to the unavailability of related data: the energy index of Russia covered oil and gas and not the whole energy sector, and lack of sufficient data for Indonesia.



Breakdown by country (Mtoe) World - 2018

Canada 2018: 526 Mtoe
% North America: 19%

United States 2018: 2,175 Mtoe
% North America: 81%

China 2018: 2,534 Mtoe
% Asia: 61%

India 2018: 588 Mtoe
% Asia: 14%

Saudi Arabia 2018: 676 Mtoe
% Middle-East: 32%

Australia 2018: 426 Mtoe
% Pacific: 94%

Source Enerdata

Figure 3: Total Energy Production

Figure 4, exposes the breakdown of the energy market of selected six countries by different colors.

Regarding China, coal accounts for the most source of energy produced having 72%, then electricity 9%, oil 8%, gas and biomass 5% each, and heat 1%. As for the US, gas is the highest source with 33%, then oil 32%, coal 17%, electricity 13%, and biomass 5%.

In case of Saudi Arabia, oil and gas are the two only sources of energy production account for 88%, and 12% respectively. In India, coal has the highest production with 49%, then biomass 34%, oil 7%, and electricity and gas 5% each.

In Canada, 50% of the energy production is for oil, 30% gas, 12% electricity, 5% coal, and 3% biomass. Lastly, in Australia 69% of the energy production is for coal, 25% gas, 4% oil, and electricity and biomass 1% each.

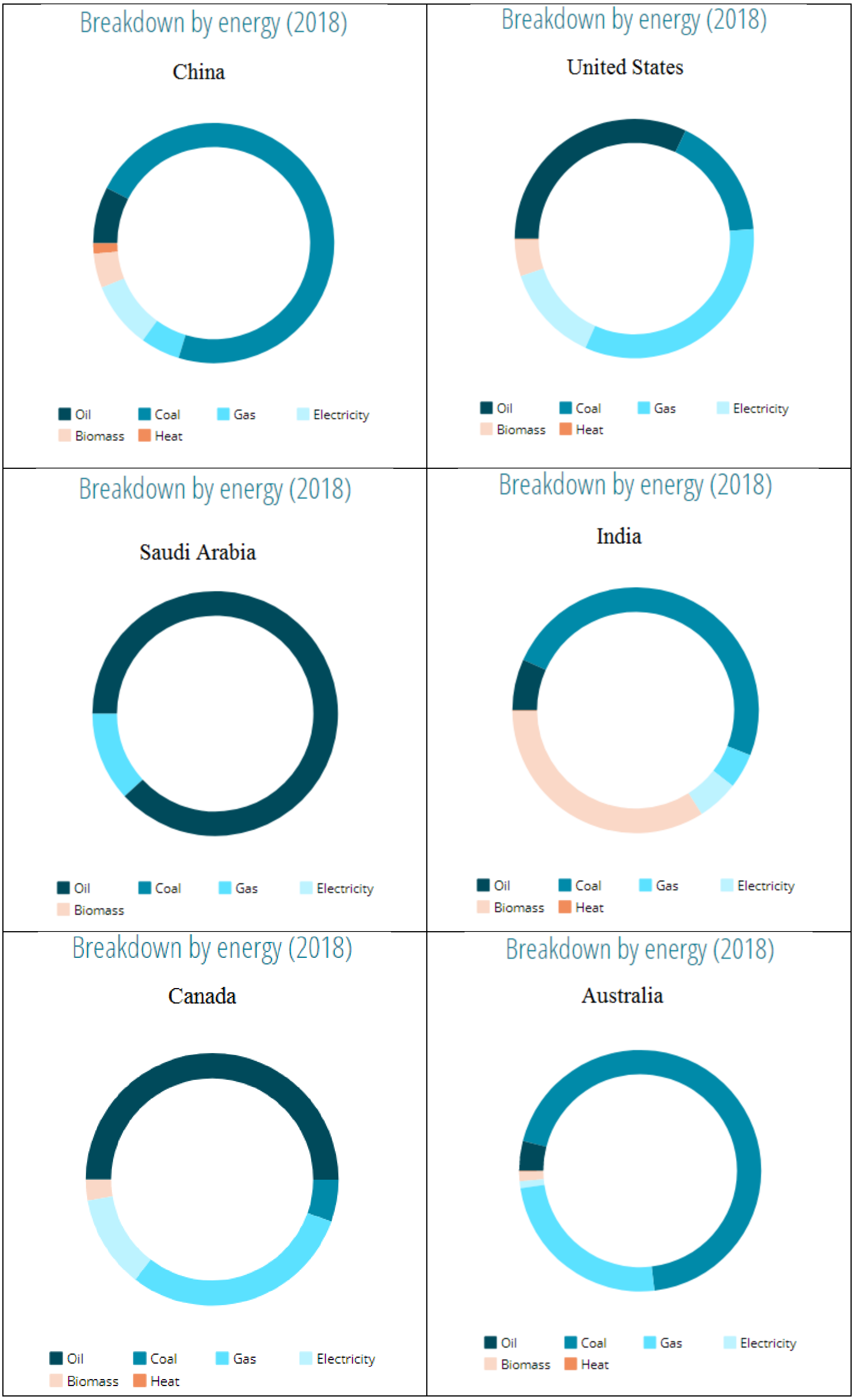


Figure 4: Breakdown by Energy’s Production

To this end, the energy indices of the mentioned countries are selected in this study. Energy indices reflect the overall performance of the sector. Investors try to avoid the volatility of energy stock by examining the energy price index as an indicator of market price fluctuations, testing the effectiveness of their investment and forecasting the trend of the energy stock market.

1.7 Structure of the Study

The remainder of the study organizes in the following manner. Chapter 2 presents the review of the literature background of the EMH and the efficiency of energy stock market, on both weak-form efficiency and, time-varying efficiency levels. Chapter 3 exhibits the data and delivers the empirical methodology applied in the study. Chapter 4 presents the empirical results and discussion, and Chapter 5 outlines the main conclusions of the study.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature concerning EMH and the efficiency of energy market on both weak-form efficiency, and time-varying efficiency levels. Meanwhile, illuminating the research gap and the contribution of the study to the literature.

2.2 The Efficient Market Hypothesis

While the EMH is usually seen as foundational to modern finance, its origin can be tracked back to Fama (1965) also Malkiel and Fama (1970). Fama (1965) defined market efficiency, when the prices wholly reflect the entire available information at any given time and investigated efficiency using the Martingale Difference Hypothesis (MDH) and Random Walk Hypothesis (RWH).

Moreover, Fama categorized efficiency as weak, semi-strong, and strong form based on the information available to market participants. In the weak-form, security prices entirely express historical prices. Therefore, the prices do not follow the repeating past patterns, so investors cannot obtain extra return solely on the basis of historical prices. In the semi-strong form, security prices completely take into account all publicly obtainable information. Thus investors cannot gain abnormal returns by tracking down the publicly available sources, as the information will already be included in the security prices. In the strong form, security prices entirety display all essential information whether there is a public access of them or not. Thus, market participants cannot make superior returns. In this study the concentration is on the weak-form efficiency of the EMH.

2.2.1 Empirical Studies on Weak-form Efficiency

Studies on weak-form efficiency adopted various statistical tests—unit root tests, variance ratio tests, long memory in nonstationary time series via MultiFractal Detrended Fluctuations Analysis (MF-DFA), long memory via fractional cointegration, non-linear dependencies, and Modified Log Periodogram (MLP) model—to examine the predictability of stock returns, and came to contradictory conclusions—even when studying the same stock markets—as a result of using different sample sizes and techniques.

The following studies are among a number of early researches on weak-form efficiency. (Fama, 1965, 1971; Jennergren & Korsvold, 1974; Fama, 1976; Korhonen, 1977; Groof, 1978; Berglund, Wahlroos, & Örnmark, 1983; Sareewiwatthana, 1986; Ekechi, 1989; Nassir, Ariff, & Mohamad, 1993; Dickinson & Muragu, 1994; Fawson, Glover, Fang, & Chang, 1996; Campbell, Lo, & Mackinlay, 1997).

Moreover, subsequent researches illustrate the more recent empirical literature on weak-form efficiency. Srinivasan (2010) showed the inefficiency of the National Stock Exchange of India (NSE India) and Bombay Stock Exchange. In 2012, Al-Ahmad explored the Damascus Securities Exchange and did not find it efficient. In Mobarek and Fiorante's (2014) study, the Brazil, Russia, India, and China (BRIC) stock markets were shown to approach the state of weak-form efficiency, displaying the prospects of BRIC countries. Mensi et al. (2017) investigated the Islamic stock market by employing MF-DFA and detected high efficiency in the long-term horizon, moderate efficiency in the short-term horizon, and minor efficiency after global financial crises.

Gil-Alana et al. (2018) implemented a fractional integration technique to focus on the weak-form efficiency of Baltic stock exchanges. They found evidence of overall efficiency in these markets, with some exceptions. In the other study, done by Ferreira, Dionísio, and Correia (2018), the efficiency of African stock markets explored using the Hurst exponent; they came to the conclusion of statistically significant serial dependency. Al-Shboul and Alsharari (2019) examined the dynamics of efficiency in United Arab Emirates (UAE) stock markets by employing the MLP fractional differencing semi-parametric model and found inefficiency in general but developments toward more efficiency.

2.2.2 Empirical Studies on Time-varying Efficiency

Most of the studies on the EMH have examined efficiency for a whole sample period and have sought to draw a conclusion about the information efficiency of the studied stock market, supposing that efficiency has a static identity. A time-varying evolution of market efficiency first presented by Emerson, Hall, and Zalewska-Mitura (1997). They investigated four Bulgarian shares by applying a multi-factor method with time-varying coefficients and the GARCH-M(1,1) model, and found different paths and speeds of movement toward efficiency. They explained that, when the market leans toward periods of efficiency, the time-varying coefficients can be expected to become noticeably smaller and more stable.

Following Emerson et al. (1997), other studies re-investigated the dynamics characteristic of weak-form efficiency (Bekaert & Harvey, 1997; Rockinger & Urga, 2000; Harrison & Paton, 2004; Pošta & Hackl, 2007). In general, the time-varying technique, used to capture the evolution and dynamic of weak-form efficiency, shows that when the market moves toward efficiency over the time path, the smoothing filter factor—which shows the time-varying manner—steadily converges to zero, hence becoming insignificant (Ito & Sugiyama, 2009; Abdmoulah, 2010; Sensoy & Tabak, 2015; Charfeddine & Khediri, 2016; Charfeddine et al., 2018).

2.3 The Efficiency of Energy Market

Regarding the topic of efficiency in the energy market a vast number of studies have tested the weak-form efficiency of energy stock market through adopting various statistical tools and came to the different conclusions.

2.3.1 Empirical Studies on Energy Market Efficiency

In early studies, Green and Mork (1991) applied the Generalized Method of Moments (GMM) on the monthly Organization of the Petroleum Exporting Countries (OPEC) prices of crude oil and disproved the presence of weak-form efficiency for the entire period of study (1978–1985); however, they found evidence of improvement over time. Serletis (1992) re-examined the unit root tests on the daily energy prices of crude oil, unleaded gasoline, and heating oil in the New York Mercantile Exchange from 1983–1990, and denied the efficiency hypothesis. In addition, the efficiency of the oil market between 1989 and 1991 disproved in a study done by Macdonald and Marsh (1993) for Group of Seven (G7 countries).

These early studies have been followed by many others. More recently, Alvarez-Ramirez, Cisneros, Ibarra-Valdez, and Soriano (2002), employed MF analysis methods on daily crude oil prices and found consistency with the RWH at time scales of days to weeks. Maslyuk and Smyth (2008) used unit root tests of Lagrange Multipliers (LMs), considering different structural breaks, on Brent and West Texas Intermediate (WTI) weekly prices for the period of 1991–2004, and confirmed the presence of the RWH in the oil price series. Charles and Darné (2009) conducted non-parametric variance ratio tests on the same two crude oil markets from 1982–2008, and discovered that the Brent crude oil market exhibited weak-form efficiency, while the WTI crude oil market was inefficient, based on a sub-sample from 1994–2008.

Wang and Yang (2010) conducted several nonlinear tests on four primary energy futures markets—crude oil, gasoline, heating oil, and natural gas—and found weak-form inefficiency in the heating oil and natural gas markets. In another study, done by Alvarez-Ramirez et al. (2010), deviation from efficiency spotted in the WTI daily prices by applying the DFA method for the period of 1986–2009. Wang and Wu (2013) examined the RWH in the WTI futures market for the period of 1985–2011. In particular, they used the MF-Detrending Moving Average method (MF-DMA) and determined the inefficiency of the crude oil market, both in the short- and long-term horizons.

Ozdemir et al. (2013) investigated the degree of persistence in Brent's monthly prices and concluded that Brent crude oil spot and futures prices had a great degree of persistence without structural breaks for the duration of 1991–2011. In addition, they found evidence of weak-form efficiency in the oil market. Recently, Górska and Krawiec (2016) examined the weak-form efficiency of WTI and Brent daily prices for the period of 2000–2015 by applying the runs test, autocorrelation, and variance ratio tests; they concluded that their results did not deliver a clear answer about whether the crude oil markets are efficient.

In 2017, the weak-form efficiency of 10 sector indices of the Islamic stock market (including the energy, healthcare, telecommunications, necessary materials, utilities, financials, consumer services, technology, and consumer goods sectors) investigated by Mensi et al., using the MF-DFA technique, for the period of 1998–2015. Their outcomes revealed efficiency in both the long and the short horizons. Lawal, Babajide, Nwanji, and Eluyela (2018) explored the efficiency of WTI, Brent, and OPEC daily oil prices for the period of 2006–2017, employing the novel Fourier unit root test, which takes into account smooth breaks and sharp shifts. They concluded that the oil market followed the unit root movements as a whole; however, the market became inefficient by the time structural breaks occurred in the model.

2.3.2 Empirical Studies on Time-varying Energy Market Efficiency

Although the topic of the efficiency of the energy market has been explored in many studies, until recently, the time-varying nature of energy market efficiency has been less addressed. Tabak and Cajueiro (2007) explored the time-varying efficiency of Brent and WTI markets utilizing the rescaled range Hurst method for the period 1983–2004 and found that both markets' crude oil prices became more efficient during the sample period by decreasing their long-memory power. Alvarez-Ramirez et al. (2008) employed Hurst exponent dynamics to study crude oil returns over the period of 1987–2007 and found the crude oil market to be consistently efficient in the long-run while inefficient in the short-run. Wang and Liu (2010) examined WTI daily prices using the multiscale DFA and rolling window methods in conjunction on a sample period of 1990–2009; they discovered an evolution toward efficiency over time, considering all horizons (i.e., short, medium, and long term).

Meanwhile, the weak-form efficiency of WTI crude oil daily prices explored by Ortiz-Cruz, Rodriguez, Ibarra-Valdez, and Alvarez-Ramirez (2012) using both the multiscale entropy technique and rolling window method, they reached the conclusion that deregulation enhanced the market's efficiency over the entire period, except for the early 1990s and late 2000s. They also stated that as efficiency declines, the likelihood of an intense US economic recession rises. Jiang, Xie, and Zhou (2014) tested the performance of WTI daily prices to determine the presence of weak-form efficiency. They found efficiency throughout the entire sample however, discovered evidence of inefficiency directly following stock market crashes (e.g., in 1985, 2008, and the Gulf War). They did so by estimating the Hurst indices of the WTI crude oil futures prices and conducting bootstrapping for the period covering 1983–2012.

Furthermore, the time-varying efficiency evolution of the crude oil prices tested by Zhang et al. (2014) using the GAR(1)-Threshold GARCH(1,1) method for the period of 2001–2013, which provided evidence of efficiency for the weekly oil return series and of irregular and varying efficiency for the daily ones. Sensoy and Hacihasanoglu (2014) used time-varying generalized Hurst exponents and the rolling window method, for the period of 1990–2013, to explore the existence of long-term dependence in energy futures markets. They concluded the presence of the time-varying efficiency in this market which changed significantly throughout the period of study.

Recently, Jebabli and Roubaud (2018) examined the energy and food markets in relation to the time-varying efficiency aspect. They applied the rolling Hurst component as well as the Threshold Vector Error Correction Method (TVECM) for the period of 2000–2015. The results showed efficiency in the long-term horizon and inefficiency in the short-term horizon for all the series. Ghazani and Ebrahimi (2019) examined the Adaptive Market Hypothesis (AMH) in WTI and Brent crude oil markets for the time of 2003–2018, by implementing the automatic Portmanteau and generalized spectral tests. Their outcomes made consistent with the implication of AMH and revealed that both crude oil markets showed the highest efficiency level.

Kristoufek (2019) replicated the study by Tabak and Cajueiro (2007) with the help of rescaled range analysis, the detrended fluctuation method, the Geweke and Porter-Hudak (GPH) estimator, and the Hurst exponent; he confirmed their results, meaning that the efficiency of crude oil markets was rejected until 1994 for both Brent and WTI. In particular, in replicating the study by Tabak and Cajueiro (2007), Kristoufek (2019) updated the analysis to include the period up to 2017, allowing for a detection of market efficiency leading up to the 2007–2009 global financial crisis and following that period, and finding that from about 2012, the market returned to efficiency until the end of the sample.

2.4 Conclusion

It apparent that the previous studies on the energy market efficiency concentrated mainly on crude oil prices. Similarly, examining the time-varying energy market efficiency through applying various linear, nonlinear, and long memory approaches. However, this study concentrates on the entire energy sector prices. Besides, exploring the time-varying energy market efficiency through adopting GARCH-M(1,1), with state space Kalman-filter estimation approach. This methodology enables to examine a smooth and continues variation in the performance of energy prices and consequently detects the dynamic of energy efficiency through time path. Particularly, it shows that when the market moves toward efficiency over the time path, the smoothing filter factor—which shows the time-varying manner—steadily converges to zero, hence becoming insignificant. Briefly, the research conducted by examining the evolution of the weak-form efficiency, based on time-varying features, of the energy markets of the most energy-producing and energy-consuming countries in the world.

Furthermore, the incorporated methodology in this study can be related to the following studies; Ito and Sugiyama (2009), estimated the time-varying autocorrelation of stock returns through moving window and state space model for US stock market, and found efficiency varies over time path. Abdmoulah (2010) tested the evolving efficiency of Arab stock market, through applying GARCH-M, and state space model with Kalman-filter. He discovered deviation from efficiency in all countries, also that the efficiency paths were not stable as a result of the contemptuous crisis. In the study done by Sensoy and Tabak (2015) the time-varying evolution of the European Union stock exchanges examined, through long memory approach. They exposed that the time-varying efficiency changed in all markets, correspondingly the 2008 financial crisis had an adverse impact on the efficiency timeline.

Charfeddine and Khediri (2016) explored the time-varying market efficiency of the GCC stock markets, through employing GARCH-M, and state-space model with Kalman-filter, besides rolling window. They exhibited the time-varying efficiency varies being affected by the subprime crisis and significantly Arab spring protest. In another study by Charfeddine et al. (2018) the same methodology applied to test the time-varying efficiency of bond markets of US, United Kingdom (UK), South Africa, and India. Results demonstrated that US bond market showed higher efficiency, and the level of efficiency changed based on prevailing crisis.

Chapter 3

DATA AND EMPIRICAL METHODOLOGY

3.1 Data Description

This study used the daily closing prices of the six major stock market energy indices (i.e., those of the US, Canada, China, Australia, India, and Saudi Arabia). The data from the US, Canada, China, and Australia collected from the Thomson Reuters Eikon DataStream, while the data from India and Saudi Arabia obtained from the website of Investing.com.

For the US energy market, the data set included data from the New York Stock Exchange (NYSE); in particular, the NYSE Energy index (NYE) used as the research object. The NYE contains major stocks of the energy sector on the NYSE that represents the entire energy sector. This data collected spans from January 3, 2003, until November 11, 2019, including 4,398 observations. Regarding Canada's data—from the Toronto Stock Exchange (TSX)—the Standard & Poor's / TSX Capped Energy index (SPTTEN) utilized. The data covers the period from January 6, 1998, to November 11, 2019, and includes 5,702 observations.

Concerning China, data from the Shanghai Stock Exchange (SSE)—and, specifically, the Shanghai Stock Exchange energy index (SSE Energy)—gathered. SSE Energy comprises the most extensive stocks in the energy sector on the SSE and aims to reflect the overall performance of the industry. The data sample covers the period from

January 7, 2005, to November 11, 2019, including 3,874 observations. For Australia, data from the Australian Securities Exchange (ASX), and specifically the Standard and Poor's / ASX 200 energy index (S&P/ASX) used. Beginning on January 1, 2007, and ending in November 11, 2019; this data includes a total 3,355 observations. The data from India collected from the NSE India (i.e., the Nifty Energy index). Spanning from February 3, 2011, to November 11, 2019, comprising 2,169 observations. Finally, the data of Saudi Arabia assembled from Saudi Stock Exchange or Tadawul—and, precisely the Tadawul Energy Index (TENI). Covering the January 10, 2007, to November 11, 2019 and yielding a total of 3,227 observations.

The beginning dates of the data sets chose based entirely on the availability of the data, however they all ended in November 11, 2019. Employing daily data is beneficial because this results in a larger number of observations, allowing to capture the entire evolution of these markets during the studied period. The countries selected based on their positions as the highest producers or consumers of energy in the world. Regarding energy consumption, China is the world's top energy consumer, followed by the US and India. With respect to energy production, China is the world's highest energy producer, followed by the US again. Then, Saudi Arabia, India, and Canada are the fourth, fifth-, and sixth-largest energy producers, respectively.

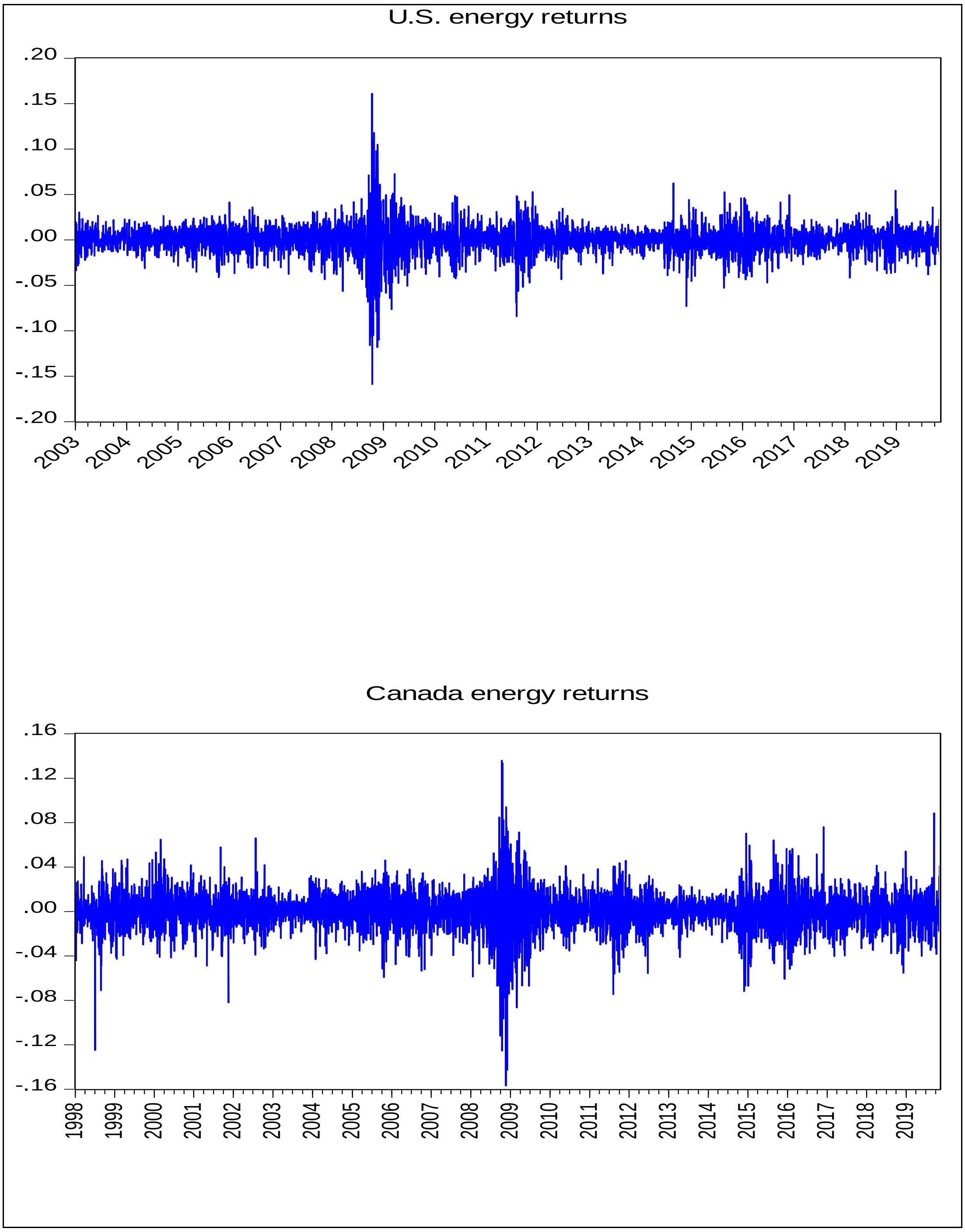
3.2 Descriptive Statistics of Data

The study converted the daily prices of energy indices into returns by computing the difference in the natural logarithms of the energy indices. In other words, the returns on day t are defined as;

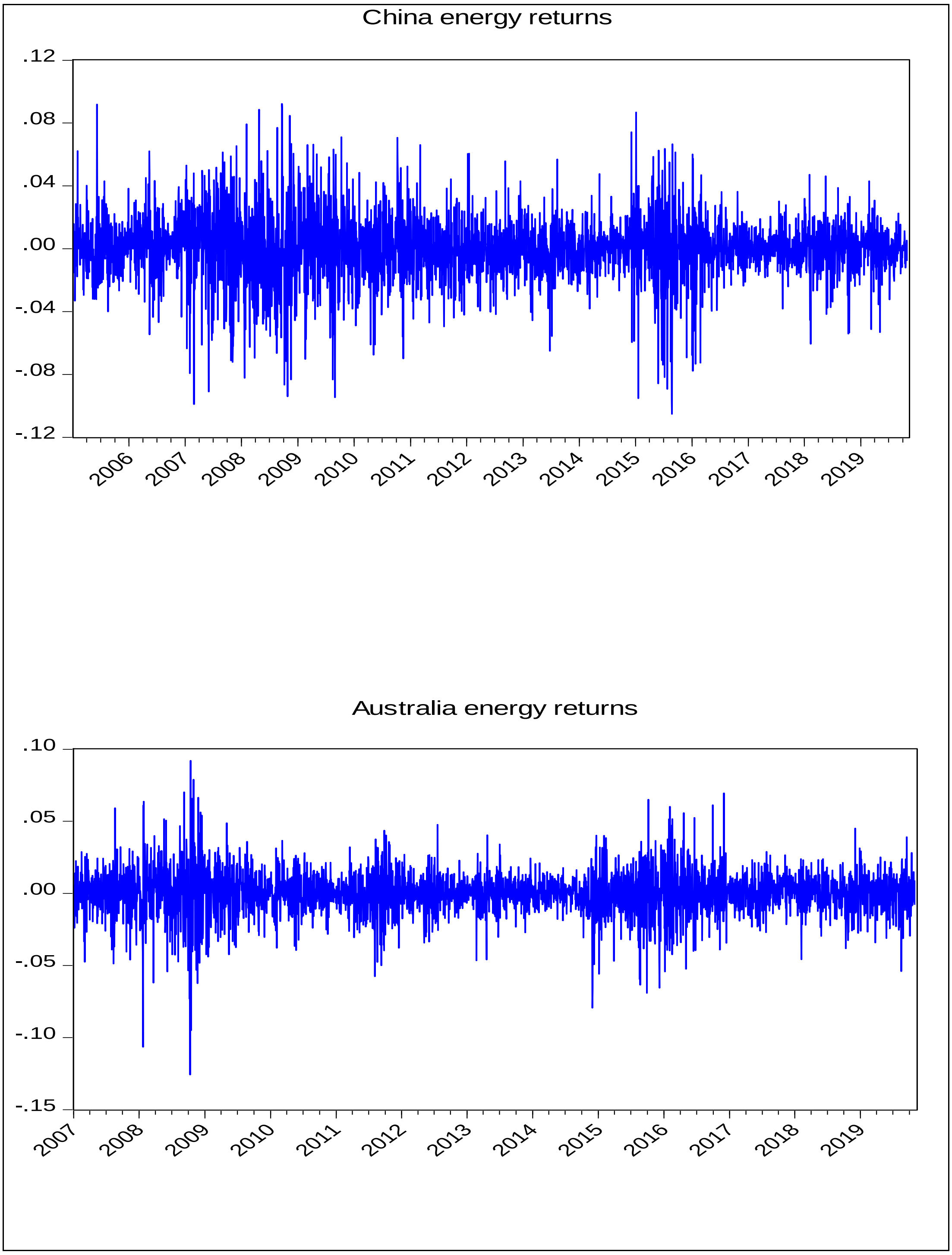
$$r_t = \left(ln_{(pt)} - ln_{(pt-1)}\right)$$

, where pt is the value of the closing price of the stock market energy index.

Figure 5, displays the energy returns for each market. In all six markets, volatility clustering appears, which indicates periods of wide swings followed by periods of comparative tranquility. Thus, in order to capture this volatility clustering, a GARCH-type model can be applied.


U.S. energy returns

Canada energy returns


China energy returns
.12
.08
.04
.00
-.04
-.08
-.12
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Australia energy returns
.10
.05
.00
-.05
-.10
-.15
2007
2008
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2012
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2016
2017
2018
2019

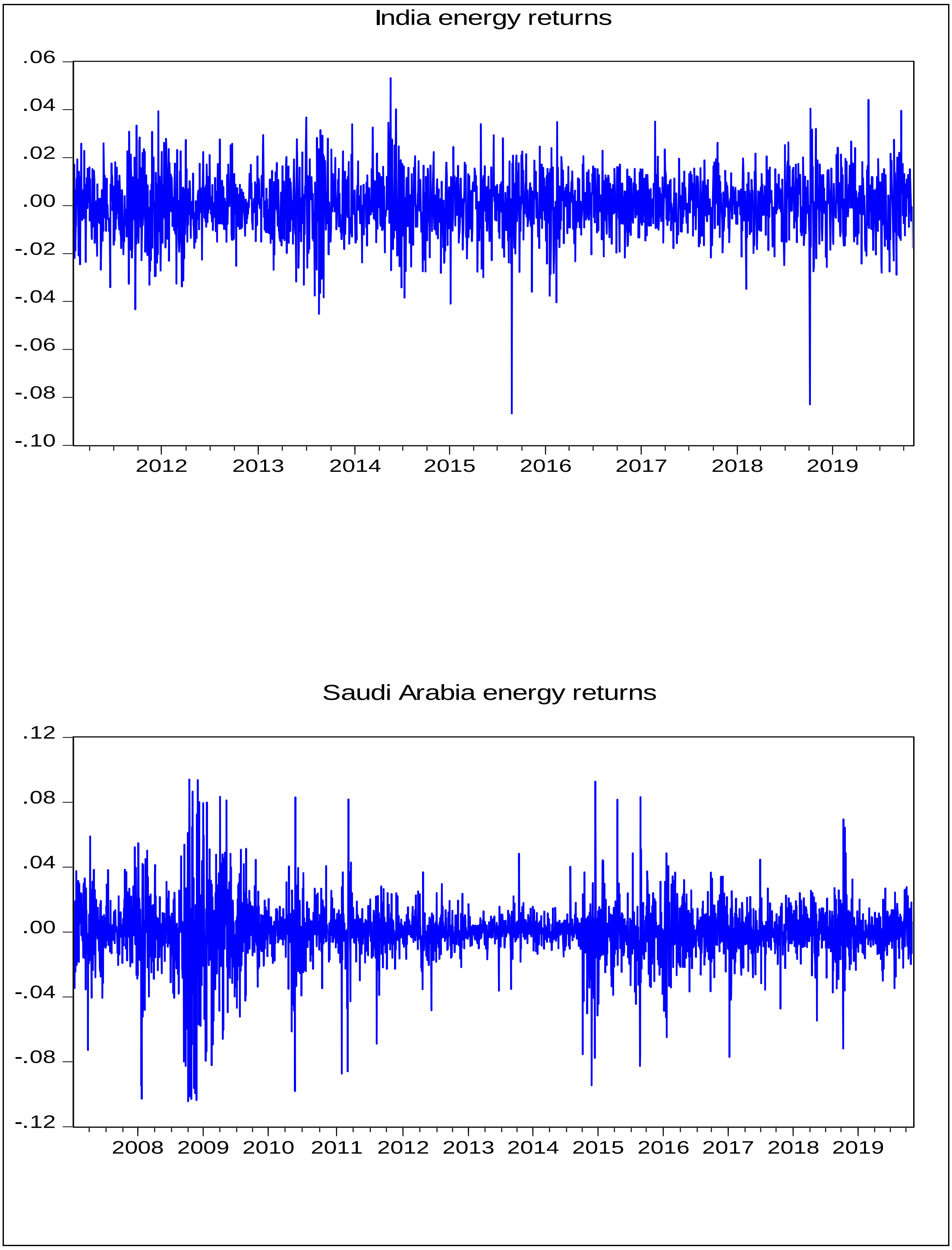


Figure 5: Energy Returns

3.3 Empirical Methodology

The weak-form efficiency requires that there should be no profit opportunities based on the past movements in asset prices. In other words, an efficient market should be an unpredictable one. In this regard, initially, the study tested this by carrying out a mean regression (Equation [1]). Then the diagnostic checks conducted.

$$r_t = \beta_0 + \beta_1 r_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim N(0, h_t) \tag{1}$$

Where, r_t is the energy returns, β_0 is an intercept, and β_1 is the slope.

3.3.1 GARCH-M(1,1) Methodology

The diagnostic tests revealed that the GARCH-type method with AR specification appropriates for examining the energy returns. The GARCH model was developed independently by Bollerslev (1986) and Taylor (1986). The GARCH model allows the conditional variance to be dependent upon previous own lag values. However, as the study aims to investigate whether the energy indices of the mentioned countries have evolved toward some degree of efficiency. Besides, the study wants to take into account that investors should be rewarded for taking additional risk by obtaining a higher return. It employed the GARCH-M model; to let the return of a security be partly determined by its risk. This model suggested by Engle, Lilien and Robins (1987), where the conditional variance of energy returns enters into the conditional mean equation.

Thus, the next step is applying the GARCH-M(1,1) model (Equations [2] and [3]). And then conducting the diagnostic checks again.

$$r_t = \beta_0 + \beta_1 r_{t-1} + \delta h_t + \varepsilon_t \qquad \varepsilon_t \sim N(0, h_t) \tag{2}$$

$$h_t = \alpha_0 + \alpha_1 h_{t-1} + \alpha_2 e^2{}_{t-1} \tag{3}$$

Equation (2), represents an Autoregressive model of order 1 (AR[1]) model, where r_t is the daily energy returns, β_0 is an intercept, β_1 is a slope, and δ is a risk premium factor when there is a tradeoff among volatility and returns in the conditional mean model. Equation (3), illustrates the conditional variance model, with α_0 as an intercept, h_{t-1} as a GARCH factor, and ${e^2}_{t-1}$ as an ARCH factor. The sum of $\alpha_1 + \alpha_2$ exhibits the degree of volatility persistence.

3.3.2 State-space GARCH-M(1,1) with Kalman-filter Methodology

It is worth to express that the approach described in Subsection 3.3.1 is static approach, which means that it assumes fixed-parameter estimation (β_1) of the conditional mean model. In order to test for possible a time-varying parameter, in this subsection, we propose to use a time-varying parameter modeling approach that provides us with a time series for the estimated (β_{1t}) coefficients. The proposed approach relaxes the restriction of the constancy of the coefficient associated with the explanatory variable, and allows for a time-varying parameter estimation. The proposed model is a state-space model (the primary benefit of employing the state-space model is that their parameters can adopt over time) estimated by using the Kalman-filter (the famous algorithms for carrying out the state-space model).

The model consists of estimating the basic equation for testing the unbiased hypothesis as a state-space model via the Kalman-filter approach. In this model, it assumed that the system's development over time is determined by an unobserved series of state vectors (β_{1t}). To obtain the estimates of the state vector, the state-space methodology uses the well-known Kalman-filter. The Kalman (Bucy) filter presents a recursive solution to filter the linear and nonlinear data (Kalman & Bucy, 1961). It is a set of mathematical equations with optimal estimator, predictor, and corrector phases, which sensibly minimize the estimation error covariance. This filter is effective for normally distributed data (Welch & Bishop, 2001). The state-space GARCH-M(1,1) model with Kalman-filter estimation, which is the time-varying model, presents in Equations (4), (5) and (6), following Hall and Urga (2002). This approach takes into account the time-varying structure variance and the dynamics of the dependency of daily energy returns.

$$r_t = \beta_0 + \beta_{1t}\, r_{t-1} + \delta h_t + e_t \qquad e_t \sim N(0, h_t) \tag{4}$$

$$h_t = \alpha_0 + \alpha_1\, h_{t-1} + \alpha_2\, e^2{}_{t-1} \tag{5}$$

$$\beta_{1t} = \beta_1\, r_{t-1} + v_{it} \qquad v_{it} \sim N(0, \sigma^2{}_i) \tag{6}$$

Equation (4), depicts a space or signal equation, with β_0 as an intercept, h_t as the return volatility, and β_{1t} as a coefficient of the first lag of energy returns, which measures the time-varying factor of energy series. This time-varying parameter, unlike in Equation (2), is not constant over time. Equation (5), portrays a state equation that defines the performance of the variance of the residuals. Equation (6), is also a state equation, describing the behavior of β_{1t} as following a random walk. In this setting, e_t and v_{it} are meant to be normally distributed, with zero as their mean and h_t and $\sigma^2{}_i$ as their variances, accordingly.

This method of estimation has also been employed by other researchers (e.g., Abdmoulah, 2010; Charfeddine & Khediri, 2016; Charfeddine et al., 2018). The use of the state-space model with Kalman-filter estimation to investigate the time-varying market efficiency of energy returns is quite important here as we are dealing with the daily long spanning date. The benefit of employing this approach is that, it measures the time-varying dynamics of the energy prices through adopting the GARCH-M method along with measuring the time-varying autoregressive factor corresponding to the daily energy prices through implementing the state-space GARCH-M method with

Kalman-filter appraisal. The time path of β_{1t} which evaluate the time-varying dependency of energy returns, represent the evolution dynamics in energy market. In particular, a time path that approaches zero specifies an enhancement of the energy efficiency.

Furthermore, the development of t-statistic over time was explored for the null hypothesis of $\beta_{it} = 0$, contrary to the alternative of $\beta_{it} \neq 0$, following Charfeddine et al. (2018). This was done to better exhibit the period of efficiency/inefficiency in the energy markets. If β_{1t} is significantly different from zero this indicates that we can forecast the future energy returns based on the current returns in other words absence of market efficiency.

Chapter 4

EMPIRICAL RESULTS AND DISCUSSIONS

4.1 Preliminary Analysis

Preliminary analysis conducted through concentrating on the descriptive statistics presented in Table 1, and the unit root test results explicated in Table 2.

4.1.1 Descriptive Statistics

The results of the analysis the descriptive statistics revealed that, over the six periods of study, the mean energy returns of China and Canada were the best, averaging 0.0803% and 0.0672%, respectively, when compared to those of India, Saudi Arabia, Australia, and the US (0.0284%, 0.0223%, 0.0210%, and 0.0153%, correspondingly). The standard deviations did not vary noticeably among the countries, being around 1.5% for U.S. and Australia, 1.7% for Canada and Saudi Arabia, 1.9% for China, and 1.2% for India. More precisely, the China energy market exhibited the highest average return, while the US market displayed the lowest. Moreover, China was the most volatile market, whereas India was the least volatile. The median was different between the countries, ranging from 0.0000% for both Canada and China to 0.0897% for Australia.

Furthermore, the skewness values were negative and significantly different from zero for all of the series. The Kurtosis values were all higher than three, indicating excess Kurtosis and fat-tailed distributions in all the energy returns. The Jarque–Bera test confirmed the outcomes of skewness and Kurtosis, and strongly rejected the null hypothesis of normal distributions (p-value = 0.000) in all the markets. Also, the number of observations range from a minimum of 2,169 days for India to a maximum of 5,702 days for Canada.

Table 1: Descriptive Statistics of Energy Returns

	US energy returns	Canada energy returns	China energy returns	Australia energy returns	India energy returns	Saudi Arabia energy returns
Mean	0.000153	0.000672	0.000803	0.000210	0.000284	0.000223
Median	0.000375	0.000000	0.000000	0.000897	0.000539	0.000431
Std. Dev.	0.015720	0.017136	0.019592	0.015676	0.012322	0.017986
Skewness	-0.367011	-0.437478	-0.302268	-0.378051	-0.396083	-0.658942
Kurtosis	14.41226	10.39717	6.640169	7.728937	5.750336	10.46842
J-b	23965.14***	13182.00***	2197.897***	3206.057***	740.3407***	7733.252***
No. Obs.	4,398	5,702	3,874	3,355	2,169	3,227

Notes: Std. Dev. is the standard deviation; J-b is the Jarque-Bera; No. Obs. is the number of observations. *** denotes to 1% significance level.

4.1.2 Unit Root and Stationarity Tests

To avoid the issue of spurious regression which leads to biased results, unit root and stationarity tests were performed. Table 2, shows the results of these tests assuming the time trend and an intercept for all of the energy returns series.

The first test implemented was the unit root one of the Augmented Dickey–Fuller (ADF) test, developed by Dickey and Fuller (1979). An important assumption of the DF test is that the error terms are *independently and identically distributed (iid)*, with constant variance. The ADF test adjusts the DF test to take care of possible serial correlation in the error terms by adding the lagged difference terms of the regressand. The hypotheses of interest are: H_0*:* series contains a unit root versus H_1*:* series is stationary. We assumed a model with time trend and an intercept and used Schwarz Bayesian Information Criterion (SBIC) as an order selection criterion. Maximum lags of 30 is chosen for all of the series. For instance, in case of the US the test statistics is computed to be -51.04. The corresponding 5% critical value is -3.41. Thus we can reject the null that the data contains a unit root.

The second test performed was the unit root one of the Phillips–Perron (PP) test, by Phillips and Perron (1988). PP uses *nonparametric statistical methods* to take care of the serial correlation in the error terms without adding lagged difference terms. This test relax the assumption of *iid*, allowing error terms to be serially correlated. The hypotheses of interest are: H_0: series contains a unit root versus H_1: series is stationary. We assumed a model with time trend and an intercept and used Newey-West Bandwidthas as an order selection criterion, for all of the series. For instance, in case of the US the test statistics is computed to be -70.28. The corresponding 5% critical value is -3.41. Thus we can reject the null that the data contains a unit root.

Finally, the third test employed was the stationarity one of the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test, by Kwiatkowski, Phillips, Schmidt, and Shin (1992). Stationarity tests have stationarity under the null hypothesis, thus reversing the null and alternatives under the ADF and PP approach. For the robustness, the results of this test compared with the ADF/PP procedure to see if the same conclusion was obtained. Here, the hypotheses of interest are: H_0: series is stationary versus H_1: series is non-stationary. We assumed a model with time trend and an intercept and used Newey-West Bandwidthas as an order selection criterion, for all of the series. For instance, in case of the US the test statistics is computed to be 0.03. The corresponding 5% critical value is 0.14. Thus we cannot reject the null hypothesis that the series is stationary.

In conclusion, the results of the unit root and stationarity tests exhibited strong evidence of stationarity in all of the energy returns. In other words, by the joint use of stationarity and unit root tests which is known as Confirmatory Data Analysis, the study confirmed all series are stationary.

Table 2: Unit Root and Stationarity Tests of Energy Returns

Test Statistic	US energy returns	Canada energy returns	China energy returns	Australia energy returns	India energy returns	Saudi Arabia energy returns
ADF	-51.040***	-73.003***	-60.731***	-55.764***	-43.954***	-53.369***
PP	-70.287***	-73.181***	-60.819***	-55.753***	-43.929***	-53.483***
KPSS	0.0366	0.0543	0.0397	0.0528	0.0333	0.0477

Notes: ADF is the Augmented Dickey–Fuller test; PP is the Philips–Perron test; KPSS is the Kwiatkowski–Phillips–Schmidt–Shin test. All the results are for both trend and intercept. *** denotes a 1% significance level.

4.2 GARCH-M(1,1) Estimations

Table 3, exhibits the results of specifying the mean equation regression (Equation [1]) and its diagnostic checks. As can be observed in all the series, serial correlation exist, which was measured using the Box–Pierce Q-statistics for both returns and squared returns. In addition, the ARCH-LM test confirmed the existence of ARCH effect in the model (Engle, 1982). Consequently, these diagnostic tests revealed that the GARCH-type method with AR specification was appropriate for examining the energy returns.

Table 3: Mean Equations of Energy Returns

	US	Canada	China	Australia	India	Saudi Arabia
β_0	0.0001	0.0006	0.0008	0.0005	0.0002	0.0002
β_1	-0.0513***	0.0337****	0.0113**	0.0373***	0.0576***	0.0617***
Q (15)	39.249***	42.955***	29.705***	21.090*	26.396**	35.375***
Q^2 (15)	5632.0***	5523.6***	920.10***	1676.4***	189.38***	2993.1***
ARCH-LM(15)	145.7957***	118.8337***	28.31372***	46.79419***	9.047469***	80.55631***
Kurtosis	14.24215	10.41786	6.602934	7.601238	5.597007	10.29899

Notes: Q (15) and Q2 (15) are the returns and squared returns of lags 15, respectively. They are the Box-Pierce Q-statistics to check the presence of serial correlation; ARCH-LM (15) is the Engle (1982) test, to check the presence of conditional heteroscedasticity. *, **, and *** denote the 10%, 5%, and 1% significance level, respectively.

To allow the variance of the error term to change over time while also capturing the risk premium, the GARCH-M(1,1) model was applied. The estimated results for the six energy indices are shown in Table 4. The results illustrated that β_0 was not significant for Canada, China, Australia, and India; however, it was significant at 5% for the US and Saudi Arabia. β_1 , which shows the dependency of daily energy returns on their lag values, was quite small in all the energy series; nevertheless, it was still different from zero and strongly significant at 1% for Canada, India, and Saudi Arabia, although it was not significant for the US, China, and Australia. The significant β_1 in three of the energy markets denotes a departure from weak-form efficiency. The value of β_1 in energy markets ranged from 0.0029 for China to 0.0644 for India.

The risk premium factor (δ) was significant at 5% only for India, given its short data coverage. Meanwhile, the ARCH and GARCH factor parameters were strongly significant in all the energy series, indicating the impact of our model.

Table 4: GARCH-M (1,1) Estimations of Energy Returns

	US	Canada	China	Australia	India	Saudi Arabia
β_0	0.0005**	0.0003	0.0003	0.0001	-0.0009	0.0005**
β_1	-0.0120	0.0591***	0.0029	0.0236	0.0644***	0.0529***
δ	0.7833	0.6112	0.7179	1.9132	10.425**	0.7306
α_0	0.00001***	0.00002***	0.00001***	0.00002***	0.00007***	0.00002***
α_1	0.9228***	0.9217***	0.9374***	0.9142***	0.8841***	0.8981***
α_2	0.0685***	0.0721***	0.0664***	0.0775***	0.0669***	0.1048***
$\alpha_1 + \alpha_2$	0.99	0.99	1	0.99	0.95	1
Q(15)	5.4614	19.785	36.949***	12.461	16.654	25.957**
	(0.978)	(0.137)	(0.00)	(0.569)	(0.275)	(0.026)
Q^2(15)	10.906	5.3781	14.154	16.832	15.318	6.3759
	(0.759)	(0.988)	(0.514)	(0.329)	(0.429)	(0.973)
ARCH-LM(15)	0.739913	0.368902	0.991081	1.146391	1.009847	0.424094
	(0.7454)	(0.9865)	(0.4614)	(0.3079)	(0.4414)	(0.9729)
Kurtosis	4.165494	6.771501	5.401569	4.608039	4.851634	9.944312
J-b	330.4811***	3495.204***	930.8653***	437.2592	354.1061	6769.922
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Notes: Q (15) and Q2 (15) are the returns and squared returns of lags 15, respectively. They are the Box-Pierce Q-statistics to check the presence of serial correlation; the ARCH-LM (15) is the Engle (1982) test, to check the presence of conditional heteroscedasticity. *, **, *** denote the 10%, 5%, and 1% significance level, respectively.

The results of the conditional variance estimations demonstrate that α_0 was strongly significant, at 1%, in all the energy returns. In addition, α_1, which measures the GARCH effect, ranged from 0.8841 for India to 0.9228 for the US, and it was strongly significant at 1% in all of the series. The impact of the ARCH effect, which was observed in α_2, varied from 0.0664 for China to 0.1048 for Saudi Arabia and was highly significant at 1% in all markets.

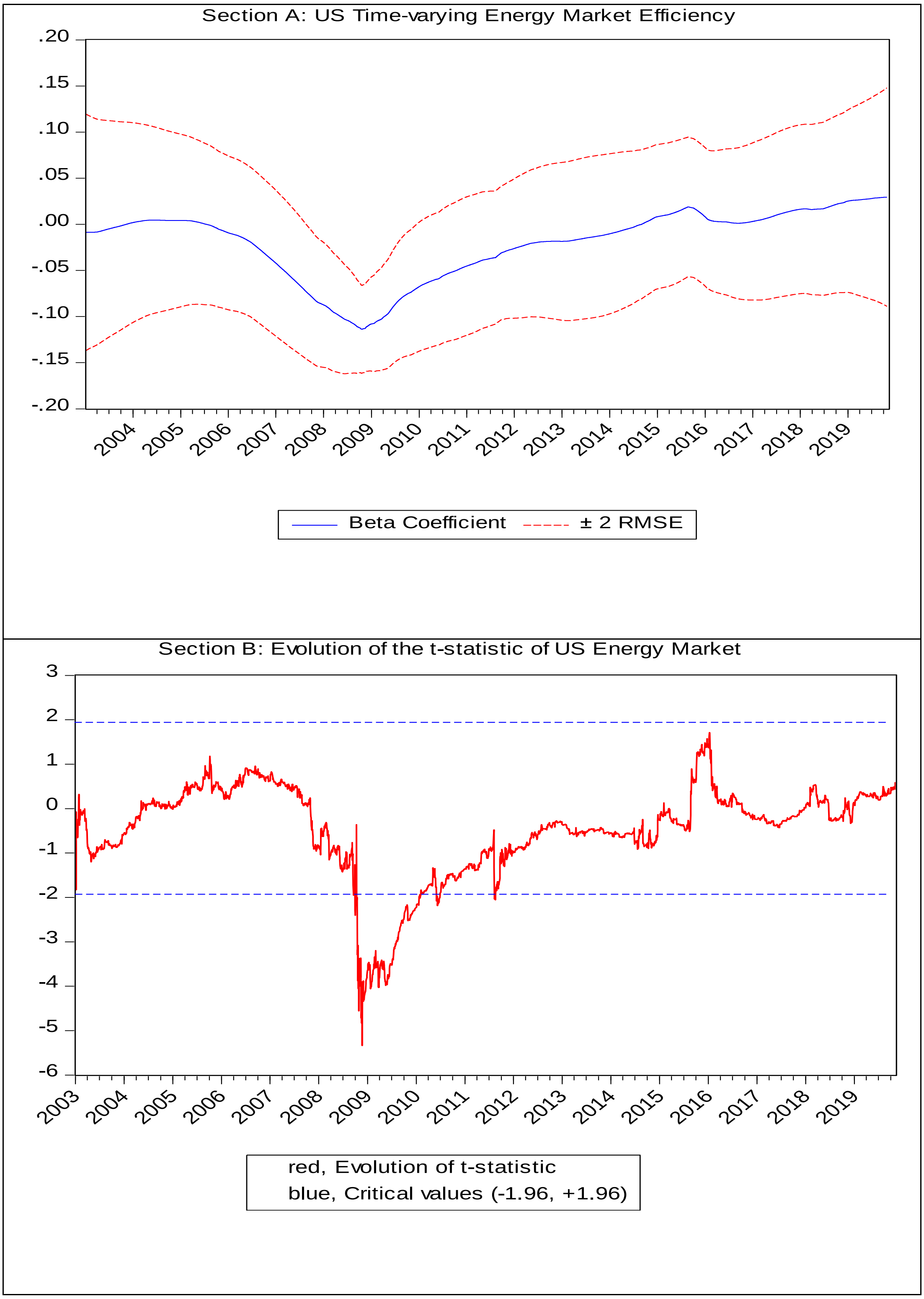
Furthermore, the summation of the ARCH and GARCH coefficients ($\alpha_1 + \alpha_2$), which measures the volatility persistence, was very close to one in the US, Canada, and Australia, and was exactly one in China and Saudi Arabia, which denotes the persistence of undesirable shock. Meanwhile, $(\alpha_1 + \alpha_2)$ indicates the structural variation or change in the state of the economy. And it opens the way to estimate the state-space model. In other words, the results of $(\alpha_1 + \alpha_2)$ which is one or very close to one in all of the series leads us to use state-space specification alongside the GARCH-M model.

Regarding the results of the diagnostic tests of residuals, the results of the Box–Pierce Q-statistic of the serial correlation and the ARCH-LM test of heteroscedasticity are no longer significant, indicating there is no serial correlation and no heteroscedasticity anymore in all of the energy series. The Kurtosis values in all of the energy returns reduced from the values realized in the mean equation regression to values attained after applying GARCH-M model, although normality was not fully achieved.

4.3 State-space GARCH-M(1,1) with Kalman-filter Estimations

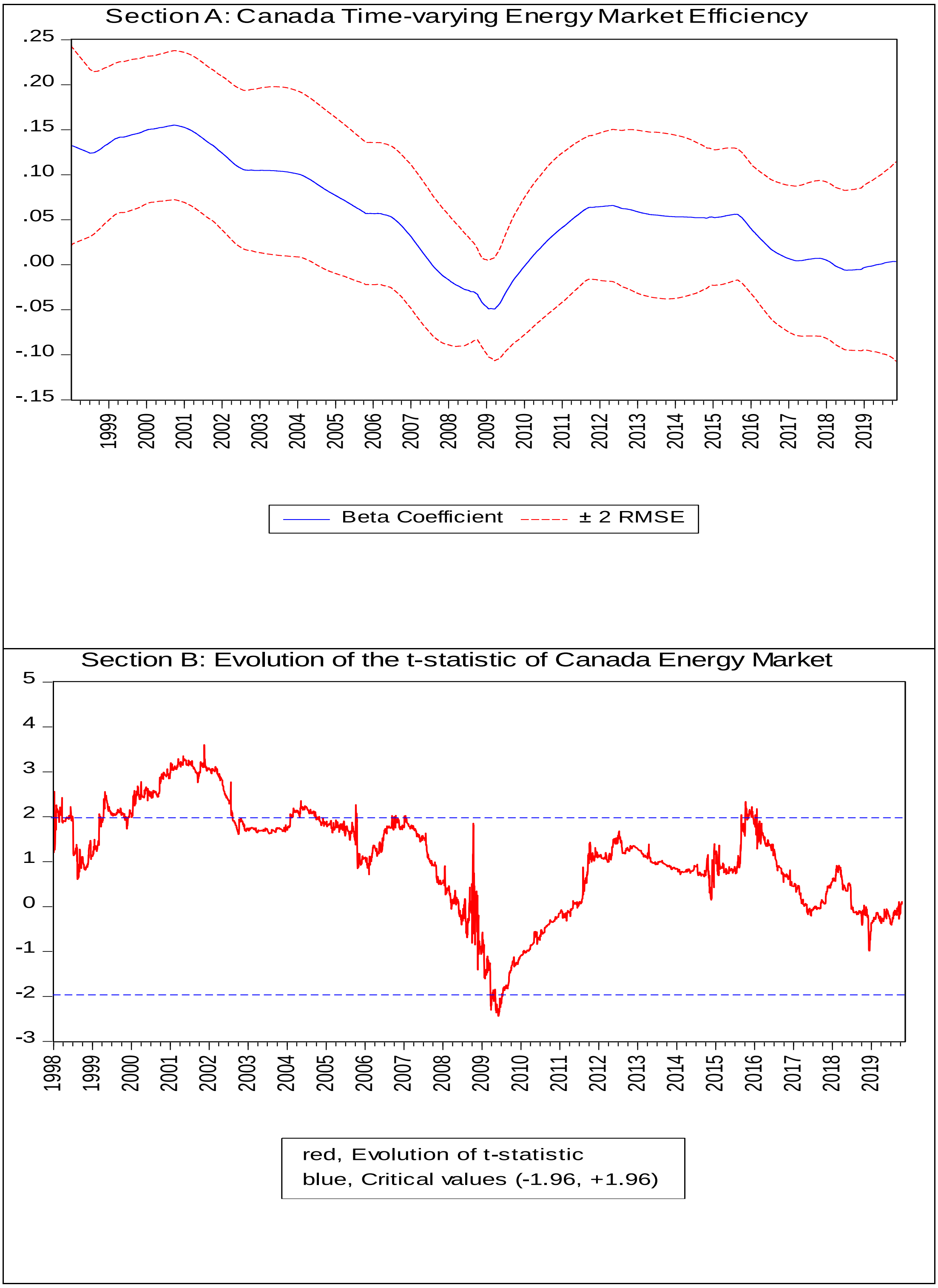
After applying the GARCH-M(1,1) model, the next step was to employ the state-space time-varying approach alongside Kalman-filter specification to explore the time path of β_{1t}, which is the time-varying parameter in the mean energy return equation and captures the dependency of energy returns on their lag values. Mainly, β_{1t} displays a more reliable picture of the energy market, rather than β_1, due to its autoregressive nature; in addition, its time-varying characteristic allows the identification of deviations from or toward market efficiency. When β_{1t} evolves and converges on zero, it indicates the improvement of energy market efficiency. In other words, β_{1t} will be larger when markets are in a more unstable condition and substantially smaller when markets move toward efficiency.

The time path of β_{1t} shows the evolution of energy market efficiency during the sample period. This dynamic is displayed in the graphs of parameters in Section A of Figures 6 to 11. These figures were created by employing smoothed probabilities and reveal the time path of β_{1t} and its 95% confidence interval after applying the state-space model with Kalman-filter estimations. Section B in Figures 6 to 11 portrays filtered probabilities of the development of the t-statistic overtime for the null hypothesis of $\beta_{it} = 0$, contrary to the alternative of $\beta_{it} \neq 0$. The outcomes clarify the evidence of inefficiency in the market when the estimated t-statistic is greater than +1.96 or lower than –1.96.


Section A: US Time-varying Energy Market Efficiency

Section B: Evolution of the t-statistic of US Energy Market

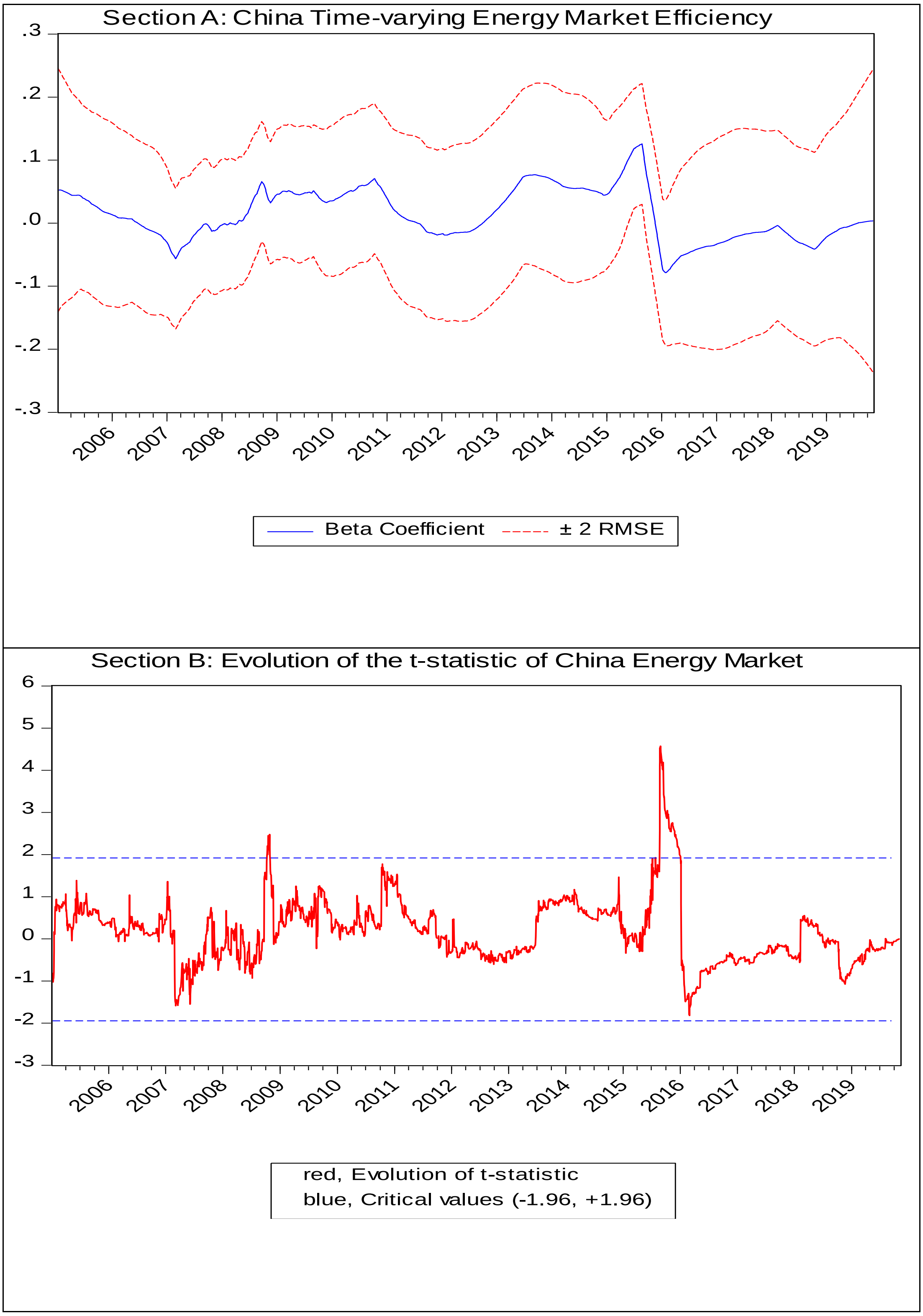
Figure 6: Efficiency Evolution of the US Energy Market



Section A: Canada Time-varying Energy Market Efficiency

Section B: Evolution of the t-statistic of Canada Energy Market

Figure 7: Efficiency Evolution of the Canada Energy Market


Section A: China Time-varying Energy Market Efficiency

Section B: Evolution of the t-statistic of China Energy Market

Figure 8: Efficiency Evolution of the China Energy Market

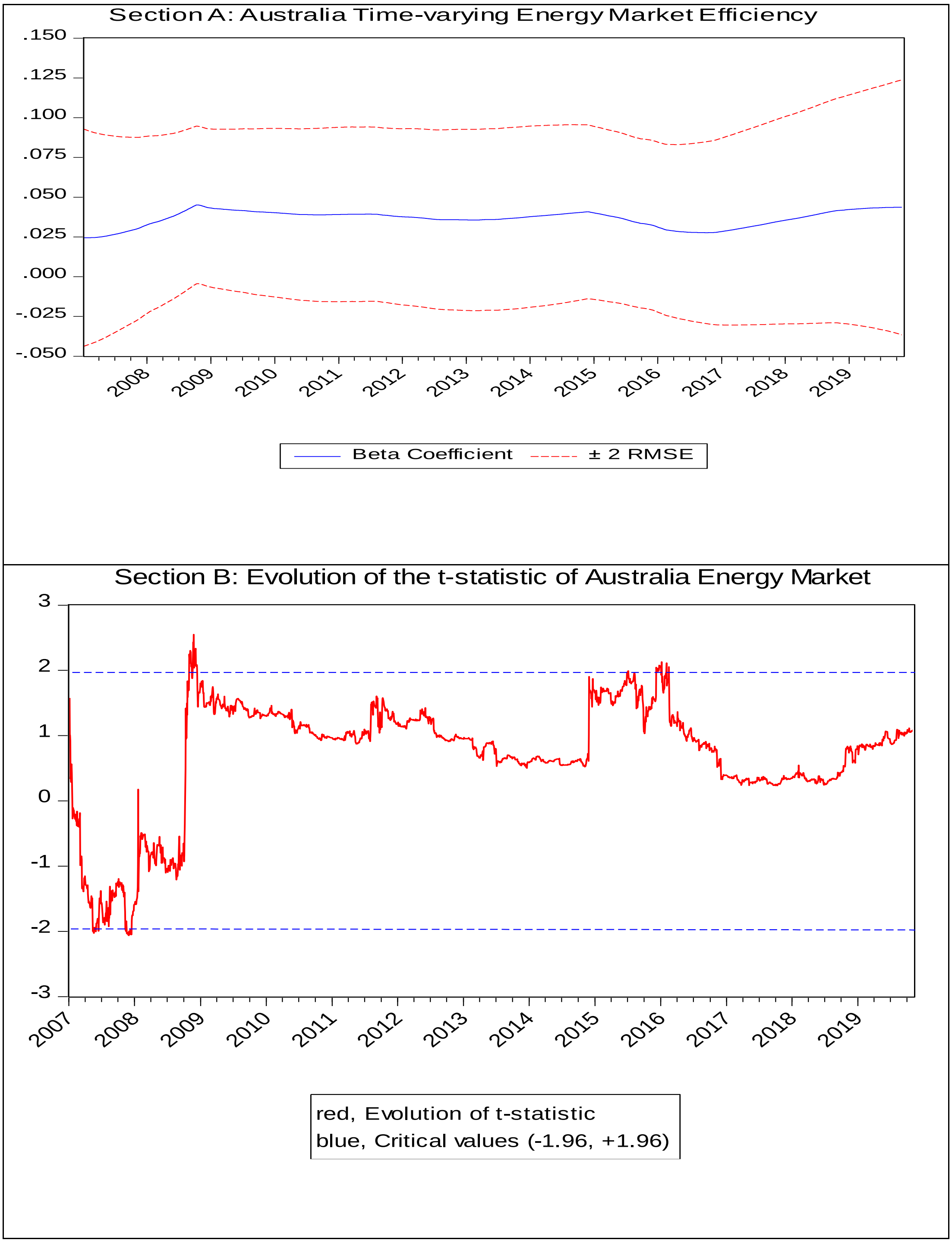


Figure 9: Efficiency Evolution of the Australia Energy Market

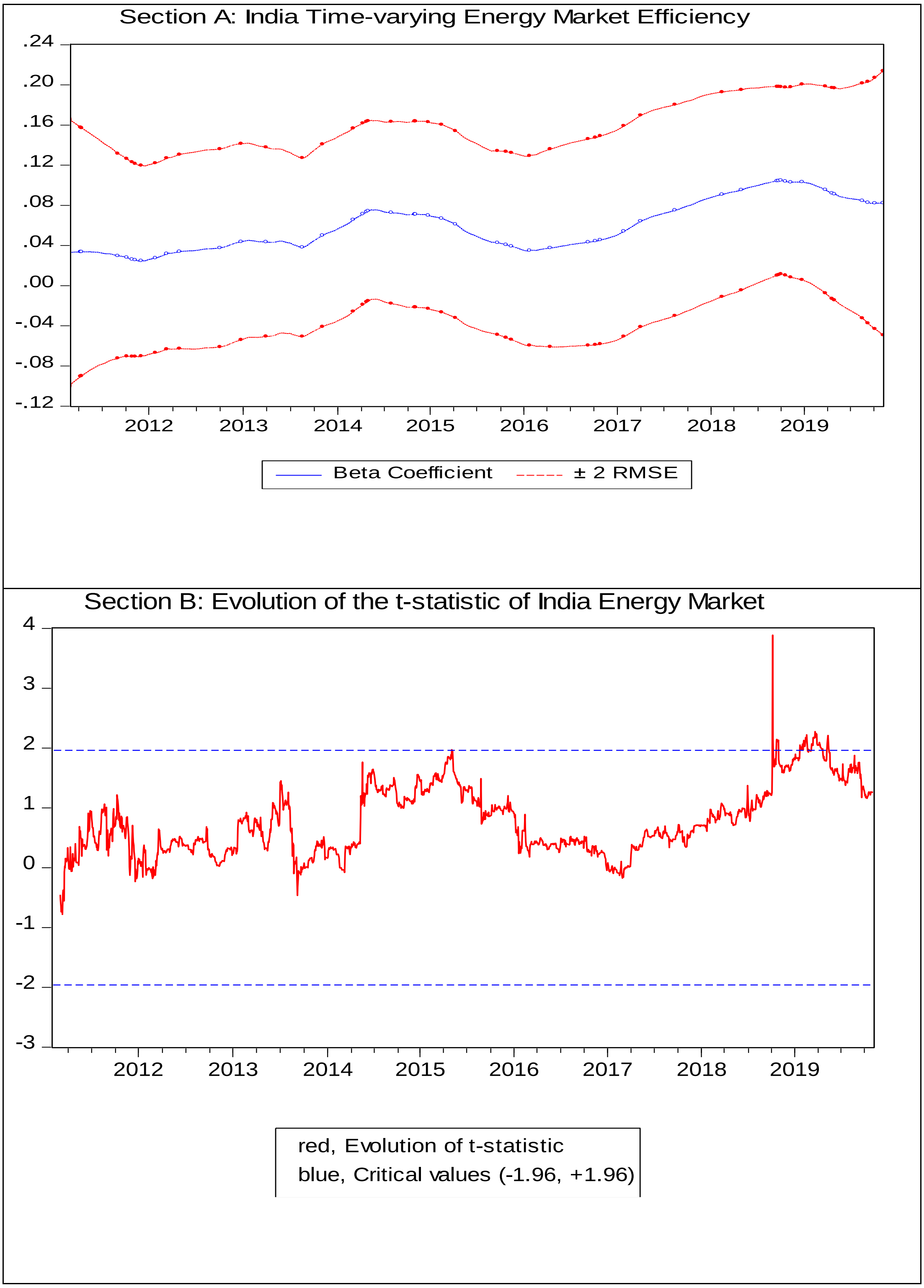


Figure 10: Efficiency Evolution of the India Energy Market

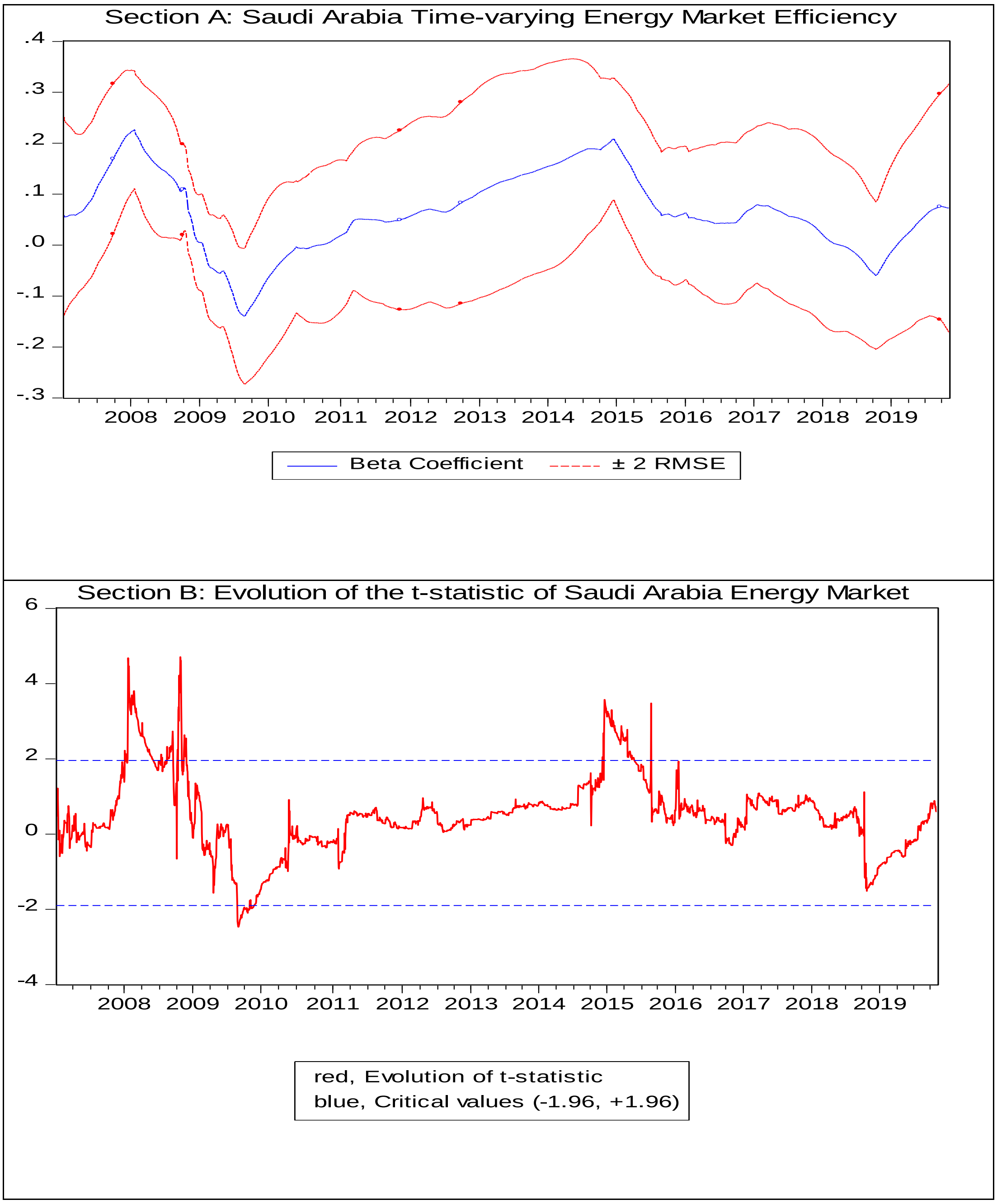


Figure 11: Efficiency Evolution of the Saudi Arabia Energy Market

4.4 Discussions

As it is apparent in Section A of Figures 6 to 11, the evolution of β_{1t} did not get close to zero, indicating that all of the energy stock markets, except for that of Australia, were unstable. Furthermore, Section B of Figures 6 to 11 demonstrated that all of the energy markets depicted some level of inefficiency for the period between 2007 till 2009, also 2015. This indicates the sensitivity of β_{1t} to the global financial crisis of 2007–2009, and the 2015 changes in the energy sector. According to Sensoy and Tabak (2015), the inefficiency experiencing as a result of crises could be due to variations in market construction and irrational behavior.

Regarding the US energy market, as shown in Figure 6, there was inefficiency in 2015 that could be attributed to the largest decline in the US energy expenditure in more than a decade; the largest decline since the 2008-2009 recession. In 2015 around 45% of the US energy expenditure accounted for the transportation sector. When the transportation sector expenditures dropped 28% from 2014 to 2015 due to decrease in fuel prices, it leads to 20% decline in the US energy expenditure, according to the eia U.S. Energy Information Administration (2019) website. More precisely, after March 2005, the US energy market deviated from efficiency, while after 2009, it steadily improved in efficiency without showing any sensitivity to the coexistence crisis (except in mid-2015); this is in accordance with the weak-form efficiency characteristic of a developed, mature market.

Figure 7, which illustrates the Canada energy market, indicates that there was market inefficiency during the time period of 1999 and 2002, which could be related to the California energy crisis that caused the first gas price spike in Canada. The rise in gas price was due to the deficiency of natural gas and electricity pipeline shutdowns according to the Canada Energy Regulator (2020). Afterward, from 2002 until mid-2008, inefficiency dramatically decreased. Meanwhile, the 2015 inefficiency can be explained by the dropping of the Canadian oil and gas industry revenue to $91 billion, nearly 40% less than 2014, which is comparable to the level experienced during the 2007–2009 financial crisis, according to National Energy Board (2016). After 2015 market went toward efficiency, which is the properties of the weak-form efficiency of developed markets.

For China, as presented in Figure 8, the evolution of β_{1t} was unstable; however, it remained steadily close to the level corresponding to weak-form efficiency. Inefficiency was observed mainly from 2015–2016, which can be explained by the China stock market crash of 2015 that began on June 2015 and ended in February 2016. Despite the rapid economic growth of China and the importance of it in worldwide trade, China stock market had exhibited low performance results following the US financial crisis. However, the stock market started to bloom from July 2014, and attracted by several investors. As in June 2015 the Shanghai stock exchange composite index amplified to 5166.35 from 2050.38 on July 2014 (Wang & Hui, 2018). Nevertheless, after this peak the market dropped extremely. The China stock index had dropped 70%; the Shanghai stock exchange composite index had fallen 32%, and the Shenzhen stock exchange component index had plunged 41%, which was the biggest collapse since 1992 (Zhao, Chen, & Zhang, 2019). This crisis raised extreme disruption in the economy and for investors, also impacted the global financial markets (Fang & Bessler, 2018).

Regarding Australia, from Section A of Figure 9, it can be seen that the time-varying parameter of the Australia energy market was small, around 0.04, and roughly constant over time, which is properties of market efficiency. However, from Section B inefficiency can be detected late 2008 and 2016. The former inefficiency can be related to Australian stock market crash of 2008—in one week the market went down by 16.4%, experiencing its worst month since 1987, according to Financial Review (2019)—, and not the global 2007-2009 financial crisis; as Australia was the only country did not affected (Meric, Taga, Gishlick, & Meric, 2015). Moreover, the later one can be attributed to the 2016 energy crisis of South Australia. On September 28, 2016, a harsh storm hit South Australia and destroyed various remote transmission towers (Lucas, 2017), consequently left about 52% damaged of wind generation network within a few minutes. This major blackout caused a financial loss of roughly 365 million Australian dollars (Yan, Saha, Bai, & Gu, 2018).

Figure 10, which depicts the India energy market, did not show any efficiency improvement throughout the whole sample, except for the period around 2015–2016. After 2016, again there was a departure from weak-form efficiency. Notably, around 2018 and 2019, the market was inefficient; this inefficiency can be ascribed to the current energy crisis in India. Although India possess remarkable fossil fuel resources, to fulfill intensely growing energy needs of the country it depends heavily on energy imports. As a result of this looming power crisis more than 40% households didn’t have access to electricity, according to eia U.S. Energy Information Administration (2019). Generally, while the time-varying parameter was somehow stable during the sample period, it was always deviate from efficiency. Thus, the India energy market cannot be described as efficient one.

Saudi Arabia’s energy market, as displayed in Figure 11, experienced an improvement in efficiency from mid-2009 to mid-2014. The country energy market was characterized by inefficiency during mid-2014 to 2016. This inefficiency can be attributed to Saudi Arabia price cycle that is a sharp drop in the oil price in mid-2014; consequently the dramatic decreased in the net oil revenue in 2015 and 2016. In Saudi Arabia around 60% of government revenue are oil-related, and the economy relies heavily on petroleum exports (Alkhateeb, Mahmood, Sultan, & Ahmad, 2017). In mid-2014, the reduction of oil price resulted in dramatic dropped in the government oil revenue, and the real GDP growth rate, according to International Monetary Fund (2017). Despite the fact that Saudi Arabia was the largest exporter of petroleum in 2016, and enhanced it production still the net oil export revenues was $133 billion in 2016, compared with $159 billion in 2015, according to eia U.S. Energy Information Administration (2019). After 2016, the efficiency was not well pronounced in Saudi Arabia’s energy market.

Overall, throughout the sample, the markets sometimes deviated from efficiency and sometimes drew toward efficiency. During periods of inefficiency, arbitrage opportunities exist due to the fact that the available information is adequate to identify the systematic arrangements of price changes. In addition to the individual crises each country experienced which significantly influenced efficiency, US financial crisis of 2007–2009 had a spillover impact on the energy markets of all countries except Australia, leading them all to experience periods of inefficiency. These finding are in line with the findings of Jiang et al. (2014). The global crisis of 2007–09 which originated in the US, later known as “Great Recession” is the longest and deepest US downturn since World War II (Meric et al., 2015). Within the studied countries this crisis hit US the most, as can be seen in Section B of Figure 6, as it experienced wide period of inefficiency.

Similarly, inefficiency was detected in all the markets in 2015, as in this year, due to two massive and permanent shifts, the energy sector changed forever: the beginning of the end of the oil age, and the fortification of the move toward alternative energy, as 196 nations agreed to sign a United Nations agreement in Paris to evade climate change.

Moreover, inefficiency possibly occurred due to investors becoming irrational when facing unexpected events, such as financial crises or unembellished recessions (Ito et al., 2014, 2016). Furthermore, Zunino, Bariviera, Guercio, Martinez, and Rosso (2016) suggested that financial crises impact the informational efficiency level of the economy. In other words, the level of informational efficiency decreases further for sectors that are more associated with the financial economy than it does for sectors that are more related to the real economy.

Chapter 5

CONCLUSION

The present study investigates whether the energy stock markets of the United States, Canada, China, Australia, India, and Saudi Arabia are evolving towards some degree of efficiency. It employs the state-space GARCH-M model with Kalman-filter estimation, also explores the development of t-statistics over time to better represent the periods of efficiency/inefficiency in the studied energy market for a period ending in November 2019.

The results demonstrate that the degree of efficiency changed over time in all of the studied energy markets; thus, they experienced periods of development toward efficiency and periods of deviation from efficiency. These time-varying changes in the level of efficiency depend largely on contemporary crises, market conditions, financial or real economic state, and the political situation.

When energy markets face global crises, such as the 2007–2009 financial crisis and the 2015 changes in the energy sector, besides the other country-related crises, such as the 2015 Chinese stock market crash, the California energy crisis, and the South Australia crisis, they have a substantial influence on the evolution of efficiency in the energy market, leading them to depart from efficiency.

Furthermore, the study finds that the degree of market efficiency varied over time and showed time-varying characteristics in all energy markets. That could be related to investors' behavioral rationality differences and to the properties of micro and macro market's framework. Besides, all the energy markets have gradually become more efficient, except for India's as a result of the current energy crisis. Particularly, the US energy market showed greater overall efficiency than the others. When the market is weak-form efficient, the likelihood that investors will obtain trading profitability based solely on historical price information becomes lower.

Briefly, understanding the dynamic efficiency of the energy market can help investors to better allocate their assets, as well as promote the economy and enhance the development of the economy.

The obtained outcomes have major implications for investors and policymakers. For investors, by considering the dynamic evolution of the energy market, they can access to more appropriate timing for their investments and better monitoring strategies; thus, they can make enhanced investment decisions. As a result investors can properly allocate their investment funds in order to achieve the perfectly capital budgeting process.

For policymakers, the efficiency observed toward the end of the period will help illuminate the practical principles that can be applied to reduce financial market disruptions and, consequently, expand and continue the informational efficiency of the energy market.

Further studies may extend this research by applying a different variety of return predictability tests in order to enhance the analysis of energy market efficiency. Additionally, they can supplement the study by also applying the AMH framework.

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APPENDIX

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RESEARCH ARTICLE

Evolving time-varying market efficiency of energy stock market

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Abstract
Energy stocks have become an essential segment of the investment portfolios of both households and institutional investors. This study investigates the dynamic aspect of evolving weak-form efficiency in six energy stock markets: those of the United States (US), Canada, China, Australia, India, and Saudi Arabia. The generalized autoregressive conditionally heteroskedastic in the mean GARCH-M(1,1) method is applied, alongside the state-space time-varying approaches with the Kalman filter estimation, to detect the evolving efficiency for periods ending in November 2019. The empirical results reveal that the studied markets undergo various extents of time-varying efficiency, containing periods of efficiency enhancement as well as periods of deviation from efficiency. Meanwhile, the 2007–2009 global financial crisis and the 2015 changes in the energy sector—in addition to other contemporaneous crises—have a profound influence on the timeline of market efficiency evolution. Overall, all of the markets gradually became more efficient, apart from India's energy market as a result of the current energy crisis in India. Amid the energy markets explored in this study, the US energy market was found to be the most efficient.

Keywords Energy stock market · GARCH-M · Time-varying efficiency · Kalman filter

Introduction

The efficiency of the security market has gained considerable attention among investors. Establishing and promoting an efficient security market enables investors to make appropriate investment decisions and better accomplish their asset allocation and portfolio risk management. The efficiency of the security market is a major factor to the improvement of the country's financial and economic sectors. The issue of the efficient-market hypothesis (EMH) has been debated in many studies, including in relation to the stock market, the bond market, and particularly, within the context of weak-form efficiency (Awad and Daraghma 2009; Alexeev and Tapon 2011; Chiwira and Muyambiri 2012; Mazviona and Nyangara 2013; Al-Khazali and Mirzaei 2017; Gil-Alana et al. 2018; Mensi et al. 2019). The inefficiency of the market makes it possible to forecast returns of security through investigating historical data, picking the undervalued and overvalued securities, and hence, bringing arbitrage opportunities into existence. In the case of efficiency, capital will move to the most productive investments. Studies have also illustrated that mature markets tend to have weak-form efficiency features, while emerging markets display different results and, hence, mostly lean toward a departure from weak-form efficiency (Abdmoulah 2010). Other studies showed the degree of association of efficiency into market size and economic development (Charfeddine et al. 2018). Furthermore, the efficiency of the energy stock market has attracted much attention (Alvarez-Ramirez et al. 2008, 2010; Wang et al. 2011; Wang and Wu 2012, 2013; Khediri and Charfeddine 2015; Kristoufek 2019), with a concentration on oil prices and a few types of energy prices. However, focusing on the efficiency of the energy market across all types of energy prices is a gap in the existing literature.

Efficiency of the energy market is defined as energy prices responding instantly to available information in the market (Lee and Lee 2009; Alvarez-Ramirez et al. 2010; Wang and Wu 2013; Górska and Krawiec 2016; Mensi et al. 2017; Jebabli and Roubaud 2018; Ghazani and Ebrahimi 2019;

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